Freshwater migration of sea trout (Salmo trutta L.) in the River Tywi during 1988, 1989 and 1990.

RT/WQ/RCEU/94/3

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INTRODUCTION AND METHODS

The results of a three year study to examine the freshwater movements of sea trout entering the River Tywi between 1988 and 1990 are examined.

Sea trout were obtained from a temporary main-river trap, estuarial seine nets and trap (jumper) nets in the outer estuary. Radio or CART (combined acoustic and radio tag) tags were inserted into the stomachs of the fish before they were released. The sea trout were subsequently detected either passively using fixed listening stations, or actively by boat, foot and air tracking.

63 sea trout entered freshwater over the three years, 10 in 1988, 23 in 1989 and 30 in 1990. Data are presented describing the fate of the tagged sea trout, their patterns of freshwater migration and the influence of environmental variables upon this behaviour. Management implications arising from these results are also discussed.

CONCLUSIONS

The weather during the main study years (1989/1990) resulted in most sea trout encountering drought conditions during the late spring and summer.

Two (3.2%) of the 63 entrants left the freshwater reaches of the Tywi before any likely spawning activity. Neither fish were located outwith the catchment and it is not therefore certain that they were non-native fish. However, even assuming that they were of non-Tywi origin, the level of 'foreign' fish entering the freshwater reaches of the Tywi (3.2%) remains low.

7.9% of the tagged population (5/63) were recaptured by rods. However, two tagged sea trout entered after the rod close season. Therefore the fishery exploitation rate was 8.2% (5/61).

27 (42.9%) sea trout went missing in-river, the majority of which disappeared from the lower sections of the river, within an area 5 km either side of the Cothi confluence. Six disappearances can probably be explained by tag failure whilst another two were known to have migrated beyond the normal tracking zone. 19 disappearances are less easily explained and probably represent undeclared capture by rods and/or illegal take.

12 entrants (19%) were classified as probable spawners with one fish recorded in each of the tributaries, Cothi, Gwili, Sawdde, Llangadog Bran and the Dryslwyn Dulais. Two fish were recorded in the Llandovery Bran and the remaining five spawned either in the main river or unmonitored tributaries. The small sample size prevented a rigorous comparison of the observed and expected spatial distribution of spawners. 15 (23.8%) of entrants were classified as having an unknown fate. It is suggested that these probably represent sea trout which had regurgitated their tags, rather than fish which died in situ. If these fish along with the tag failures, the fish which went beyond the tracking zone and the known regurgitations are added to the 12 fish above, this raises the proportion of probable spawners to ca. 60% of freshwater entrants.

Freshwater entrants exhibited discrete patterns of migration. Sea trout entering during the spring summer exhibited a period of initial upstream migration followed by a quiescent period. The time in quiescence varied from 5.1 to 144 days, with some sea trout ignoring freshets during this period. Some sea trout demonstrated more than one quiescent stop, migrating upstream in discrete stages. After this holding behaviour secondary migration occurred, usually taking the fish to its spawning area in the autumn. Sea trout entering later in the year (October) were recorded migrating straight to the spawning areas, only stopping for short periods.

Overall, the majority of sea trout (60%) exhibited quiescence in the lower river with 30% and 10% in the middle and upper river, respectively. Since some sea trout did not migrate to their final spawning destination until after the end of the rod season, some fish migrating through the middle/upper river were unavailable for capture by rods in these reaches of the river.

Of the five rod recaptures over the three years, none were taken within 43 days of entry. Two were taken whilst quiescent and another whilst it was last detected moving. The remaining two fish had regurgitated their tags and the migration stage at recapture was therefore unknown. This extended period between entry and recapture suggests that sea trout, unlike salmon, remain susceptible to rod recapture for many months after entering fresh water.

Sea trout entering earlier in the year tended to migrate further before becoming quiescent, and spawned higher in the catchment.

Sea trout migrating in the lower and middle river were biased towards moving at night when flows were $<20\ m^3 s^{-1}$. This infers a preference for migrating under lower light conditions, and is an extension of the similar behaviour in the estuary.

No relationship was demonstrable between the mean daily flow (MDF) on entry and the distance migrated before becoming quiescent. Secondary movements were biased towards periods of freshets, but from the small quantidy of data available no apparent preference was demonstrable for a certain magnitude of freshet. Sea trout did appear to demonstrate a temporal responsiveness to freshets with the likelihood of fish moving being high in April/May, decreasing through the summer and increasing again in October, as the spawning period approached.

10 (83%) probable spawners were recorded moving downstream as kelts, seven of which were recorded as far downstream as the tidal limit. This suggests that 58% of kelts survive to reach tidal water. Elevated flows were considered important in aiding the emigration of kelts, with downstream movements biased towards night-time.

Given the preference for migrating at night, it is not known whether the predominantly night-time abstraction restricted the rate of upstream migration for fish downstream of the abstraction, since sea trout may have migrated further if flows had not been further reduced. The sea trout tracks demonstrated that the majority of sea trout (65%) undertook quiescence upstream of the abstraction point at Nantgaredig. These fish would not therefore have been affected by the diurnal variation in flow following the period of initial entry. It is therefore likely that any effect of abstraction on sea trout migration in the Tywi is inclined to be biased towards modifying the success of migration through the estuary.

A large proportion of fishing effort for sea trout by the rods takes place at night. Diurnal changes in the flow pattern caused by night-time abstraction may therefore be detrimental to fishing success downstream of the abstraction point. Daily fluctuations in river flow by night-time abstraction could therefore reduce the exploitation rate of sea trout located below the abstraction point.

RECOMMENDATIONS

The study indicates that the Tywi rod fishery exploits almost exclusively sea trout of Tywi origin. Catch estimates will therefore not need adjusting before assessing productivity within the catchment.

The spatial exploitation of the in-season stock by rods should not necessarily be used as an indicator of intra-catchment productivity.

Since sea trout remain susceptible to rod recapture for long periods after entering freshwater, analysis of rod catch data as catch per unit effort (CPUE) should not be used as a measure of the within-season timing of sea trout entry.

The current rod (and net) season covers a large proportion of the run period of sea trout on the Tywi (March-December). Sea trout entering later in the year (October-December), which include delayed spring migrants, will not however be available for capture. However, due to the high proportion of the extant stock which enters within the season, comparison of annual catch per unit effort may provide an indication of abundance/stock size.

Illegal exploitation may have accounted for a number of fish in 1988 and 1989. Given the spatial distribution of sea trout, enforcement should be concentrated within the lower river during the spring/summer. However, a considerable proportion of sea trout (40%) became quiescent in the middle and upper reaches, and therefore enforcement also needs to be targeted in these areas.

If artificial releases are to be used for stimulating movement of adult sea trout, the temporal response of fish to freshets needs to be considered. The use of artificial releases in the summer months (July-September) is less likely to stimulate in-river sea trout to move. Artificial releases, to stimulate movement amongst in-river sea trout, would be better utilised by augmenting low flows during the spring or the autumn. A management plan for artificial releases from Llyn Brianne should also reflect the best practice for adult salmon, and all juvenile stages of both species. It should also take account of the estuarial behavioural requirements.

There is a need for further studies to investigate the small scale movements of sea trout above and below abstractions.

There is a need for further studies to investigate the freshwater movements of the younger sea age classes of sea trout. Tracking smaller fish will require suitable (smaller) radio tags and may also necessitate a different tagging methodology, e.g. peritoneal cavity tagging.

1. INTRODUCTION

The sea trout (*Salmo trutta* L.) stocks within Welsh rivers represent an important resource, supporting direct employment for net fishermen and providing a sport fishery on which is centred a large and expanding tourist industry. The River Tywi is the Principality's most important and prolific sea trout fishery, with an average annual declared sea trout rod catch of 5194 fish (1987-1991). It is also famed for its large average size of sea trout, due to a combination of good marine growth and longevity (Harris, 1970; Evans, 1994).

The development of underwater biotelemetry, and in particular radio and acoustic tracking technology, has enabled the migration patterns of salmon to be studied in estuaries (e.g. Potter, 1988; Solomon & Potter, 1988; Clarke *et al.*, 1994) and within rivers (e.g. Clarke & Purvis, 1989; Webb & Hawkins, 1989; Milner, 1990). Tracking adult salmonids during their freshwater phase can provide valuable information for stock management purposes (Clarke & Gee, 1992).

Since sea trout are typically smaller than salmon, they pose additional problems for radio tracking. Early tracking studies of sea trout using stomach tagging demonstrated limited success, due to a high level of tag regurgitation (Solomon & Storeton-West, 1983). Mounting the tag externally also presents difficulties due to the requirement for small tags and the possible effects of swimming impairment, infection and subsequent damage associated with the attachment technique (Varallo, 1988). As part of a major tracking exercise with salmon on the Tywi (Clarke *et al.*, 1994), a pilot study was undertaken in 1988 where 12 relatively large (>500 mm) sea trout were stomach tagged in-river. Initial results indicated that these sea trout could retain stomach tags for considerable periods. As a consequence, the study was extended and enlarged in 1989 and 1990.

2. OBJECTIVES

This report is one of a series describing results from a three year study of salmonid migration in the River Tywi. It concentrates on aspects of sea trout migration within the freshwater reaches of the catchment, with the following specific objectives:

(i) To provide reliable and quantifiable information regarding the effect of flow on migration.

(ii) To identify the extent to which the water bank in Llyn Brianne may be used to promote migration in the mainstream Tywi.

(iii) To examine the fate and spatial distribution of sea trout entering the Tywi.

(iv) To provide basic data describing the behaviour of sea trout in rivers.

3. THE TYWI SYSTEM

3.1 Fresh water

The River Tywi (Fig. 1) rises at a height of 425 m in an afforested and moorland area of mid Wales. It is 111 km in total length and has a catchment area of 1376 km^2. Average daily flow (ADF) for the Tywi at its mouth is 45 $m^3 s^{-1}$ (1975 - 1989), although in 1989 mean daily flow (MDF) dropped below 2 $m^3 s^{-1}$. A regulating reservoir, Llyn Brianne (catchment area 88 km^2), is situated in the headwaters of the River Tywi some 19 km north of Llandovery. Major abstractions for potable supply occur at Manorafon and Nantgaredig (Fig. 1), the latter supplying nearby Carmarthen and much of the Swansea area. Abstraction at Nantgaredig occurs predominantly at night, and as a result considerable diurnal variations in freshwater discharge to the estuary may occur during periods of low river flow.

The water quality is generally good (NWC class 1A), except for the headwaters which have been shown to be vulnerable to acidification (Stoner *et al.*, 1984; Edwards *et al.*, 1990).

4. MATERIALS AND METHODS

4.1 Fish capture

Three methods were used to provide sea trout for radio-tagging:

(i) Seine netting

Sea trout were purchased from the commercial seine netsmen operating within the lower estuary in the vicinity of Ferryside (Fig. 1; see Evans *et al.*, (1994) for a full description). These were fish which would otherwise have been killed and sold. Undamaged sea trout were chosen for tagging and released immediately, close to the point of capture.

(ii) Jumper netting

The second technique involved the use of fixed engines known as jumper nets. Up to three of these trap nets were positioned intertidally at St. Ishmaels (1 km downstream of Ferryside; see Evans *et al.*, (1994) for a full description).

(iii) Temporary trapping

Sea trout were captured in 1988 by a temporary inscale trap (bar width 35 mm) located at Cystanog Farm, 19.8 km from Ferryside (Fig. 1).

4.2 Tagging procedure

Sea trout of suitable size (>500 mm for radio-tagging and >600 mm for CART tagging) and in good condition (i.e. no fresh net marks, minimal scale loss, no predator marks and no obvious signs of stress or fatigue) were selected for tagging. Once selected, the fish were removed from the net and placed into plastic-coated canvas handling bags containing sea water and anaesthetic (2-phenoxyethanol, about 100 ppm dissolved strength). Once under anaesthesia, the fish were measured (fork length to the nearest 5 mm), sexed and scale samples (2 scales) taken for subsequent ageing. Each sea trout then received two types of tag:

(i) Internal transmitting tags

The internal tags used were Ministry of Agriculture Fisheries and Food (MAFF) designed radio tags or combined acoustic and radio tags (CART) (Potter, 1988; Solomon & Potter 1988). Radio tags comprise a uniquely identifiable transmitter and battery contained within a small (50 x 16 mm) polycarbonate cylindrical tube with biconvex ends. The radio tags transmit a pulsed radio signal in the frequency range 173.805 to 173.850 MHz.

Tags were lubricated (KY Jelly) prior to insertion into the stomach of the anaesthetised fish, via the oesophagus, using a purposely designed plunger. The tag was released and the plunger removed at the first sign of resistance.

(ii) External marker tags (Floy tags)

An external Floy tag was attached to each fish just below the dorsal fin, using a "Minitachit" gun. These "t-bar" tags had 50 mm plastic (orange) sections which bore a printed message indicating the presence of a transmitting tag in the fish's stomach.

(iii) Recovery

Following tagging, fish were allowed to recover at the point of tagging by orientating them into the current. They were allowed to regain equilibrium and only released when they actively swam away.

4.3 Tracking

Two basic methods of tracking radio-tagged sea trout provided most of the data for this study:

(i) Automatic monitoring

MAFF designed automatic listening stations (ALS), or 'scanners', (Solomon & Storeton-West, 1983) were sited at roughly equidistant intervals throughout the estuary, main river and the lower reaches of major tributaries. Up to 36 scanners were deployed during the study (Fig. 2). These units allowed for individual fish to be identified and were programmed to scan for the presence of tags/fish at either 2 or 5 minute intervals.

(ii) Active tracking

This involved the use of a variety of modes of transport (cars, boats, walking and light aircraft) in conjunction with a hand held, preset radio (Yaesu FT-290R). This enabled accurate location of radio-tagged sea trout. Weekly boat tracks were conducted over 25 km of the fresh water section of the river between Llandeilo and Carmarthen (see Ellery & Clarke (1992)). Boat tracks were also undertaken over a further 22 km of the main river, between Llandovery and Llandeilo, though less frequently (fortnightly/monthly).

Aircraft based tracks were also undertaken during the autumn/early winter period of each year. These covered the Tywi and its tributaries as well as the main river reaches of the major catchments from the Teifi in the East to the Afan in the West (Ellery & Clarke, op. cit.).

Fish locations were recorded by reference to points marked on 1:50000 Ordnance Survey maps. Fish movements were expressed in terms of the linear distance upstream from Ferryside (0 km, Fig. 1), unless otherwise stated.

4.4 Assumptions

Two assumptions are implicit in the study of migratory fish movements using biotelemetric techniques. First, the sample of fish tagged are representative of the population as a whole, and second, the fish are not adversely affected by the capture/tagging process and display normal behaviour patterns after tagging.

The minimum size for tagging (>500 mm) resulted in selecting for the larger sea trout from the stock (Mee *et al.*, 1994). This biased the tagged sample towards the older sea age categories, although the only sea age group to be completely excluded was that of whitling (.+, first post-smolt summer). The next smallest sea age group (.+SM+, those which had previously spawned in their first winter after smolt migration) was included. Although it must be recognised that extrapolation of results in this study to the younger sea age group may not be totally appropriate, in the absence of data describing behaviour of whitling, managerial decisions must be based on the best available information.

The assumption that tagged adult fish behave normally after tagging is almost impossible to prove directly. Whilst some short-term interruption during the tagging process is accepted, the longer term implications are unclear. Tagged sea trout were recorded displaying 'normal' spawning behaviour and in some instances radio-tags were retrieved from dead kelts.

4.5 Controls

4.5.1 Tag failure experiment

To enable assessment of tag failure rates and appropriate correction of data, 43 radio tags were randomly selected from batches during 1989 and 1990. These tags were allowed to transmit in a water bath of ambient temperature at a depth of 1 m. Weekly checks on pulse rates, frequency range variations and signs of water ingress would indicate tag failure (Mee & Clarke, 1992).

4.5.2 Regurgitation experiment

10 radio-tags were deployed at various points throughout the main river and their subsequent positions monitored at weekly intervals. This experiment simulated the regurgitation of radio-tags, determining (i) Whether such tags would remain stationary, move with flood events and (ii) whether they would fail due to physical damage.

4.6 Environmental data

Hydrological data were obtained from a gauging station at Nantgaredig (Fig. 1) and supplied by the NRA SW Divisional Hydrological Section.

4.7 Data analysis - Protocol for interpretation of data

4.7.1 Spatial classification of the main river

The main river was classified into three sections (see Fig.1):

Lower river - From scanner site TY1 (13.5 km, NGR SN 408197) to Dryslwyn road bridge (36.5 km, NGR SN 553203), a distance of 23 km.

Middle river - From Dryslwyn road bridge to Llangadog road bridge (62 km, NGR SN 637220), a distance of 35.5 km.

Upper river - From Llangadog road bridge to Llyn Brianne reservoir (92 km, NGR SN 793484), a distance of 30 km.

4.7.2 Fate of sea trout entering fresh water

The fate of each sea trout entering fresh water was classified as follows:

"Left before spawning"; Fish which were last detected moving downstream, towards or within the estuary, prior to any likely date for spawning activity (mid October).

"Missing in river"	; Sea trout tracked in fresh water for a period of time but were subsequently undetected within the tracking period. These fish were not reported as recaptures.
"Rod recapture"	; Fish reported recaptured by anglers.
"Probable spawner"	; Sea trout moving upstream or into monitored tributaries between mid-October and December were deemed probable spawners. For many of these fish this classification was supported by subsequently tracking the fish moving downstream as a kelt.
"Unknown fate"	; The fate of these fish could not be ascertained from tracking data. Fish in this category did not satisfy the criteria for any of the other categories. The category was typically represented by tags stationary at the time when all tracking activity ceased, many of which had been recorded stationary for a considerable period.
"Regurgitated"	; Regurgitation, confirmed either from recapture or retrieval of the tag.
"Found dead"	; Sea trout found dead in the freshwater reaches of the Tywi (not as recaptures).

4.7.3 Freshet events

Freshet events for each year were identified from the annual hydrograph. The start, peak and end date/time of each freshet was interpreted from the flow recorded at Nantgaredig (15 minute resolution). For freshets which occurred back-to-back, each individual peak in flow was defined as a freshet. The start, peak and end date/time for each individual freshet was taken as the date/time of the trough, peak and subsequent trough of the hydrograph, respectively.

4.7.4 Diurnal period

Each 24 h period was divided into day and night according to the sunset/sunrise times for Swansea (data supplied by the Science and Engineering Research Council). Observed movements past fixed locations could therefore be described as during the day or night period. The expected frequency of movements past scanners (assuming no diurnal influence) was calculated to enable statistical analysis using the Chi^2 test. For each fish, the probability of movement on that day in each diurnal period could be calculated from the ratio of the available day and night hours. The total number of expected day and night movements at each location could then be calculated from the cumulative probabilities of the individual fish.

5. RESULTS

5.1 Freshwater discharge

High rainfall throughout the summer of 1988 maintained abnormally high base flows in the Tywi during the period July to September, with mean daily flow (MDF) ranging from 4.3 $m^3 s^{-1}$ to 119.3 $m^3 s^{-1}$ (median 27.1 $m^3 s^{-1}$). The seasonally high rainfall ceased during September 1988 and river flows subsequently remained at levels below the seasonal norm for the spawning season (Fig. 3).

In contrast, the dominant feature during the experimental period of 1989 was an almost complete lack of rainfall during the period May to September, resulting in extreme low summer flows (Fig. 3). During the spring period (April to early May), river flows, although falling, were at normal levels following a wet March. From May onwards, apart from a spate in mid September, drought conditions prevailed until the middle of October, with the first major rainfall occurring after the cessation of both rod and net fishing seasons. During the drought period, MDF at Nantgaredig gauging station fell to a minimum of 1.01 $m^3 s^{-1}$. The average MDF between July and September was 6.1 $m^3 s^{-1}$, markedly lower than the long term average (1979-1990) for the same period of 18.9 $m^3 s^{-1}$, and similar to the corresponding values in the acknowledged drought years of 1976 and 1984. Three artificial freshets were released from Llyn Brianne during the drought period; 19-21 July (maximum release of 10 $m^3 s^{-1}$) resulting in a peak flow at Nantgaredig of 9.7 $m^3 s^{-1}$, 10-14 August (maximum release of 15 $m^3 s^{-1}$) peaking at 33.5 $m^3 s^{-1}$, and 28 September - 2 October (maximum release of 15 $m^3 s^{-1}$) peaking at 28.7 $m^3 s^{-1}$ (coinciding with a natural freshet).

A similar drought period existed in 1990, with base flows remaining low throughout the summer months and only rising with heavy rainfall during the autumn (Fig. 3). River flows fell to a minimum of 2.71 $m^3 s^{-1}$ during the summer of 1990, with average MDF in the period July to September of 8.45 $m^3 s^{-1}$ (affected by one flood event with a maximum of 70.8$m^3 s^{-1}$). Amenity releases from Llyn Brianne were not undertaken in 1990 since release water was potentially toxic to both juvenile and adult salmonids below the reservoir, due to a combination of low pH and elevated aluminium levels (Rogers, 1990).

5.2 Age structure and seasonal distribution of tagged sample

The behavioural data presented are based on 10 radio-tagged sea trout which entered fresh water in 1988, 23 in 1989 and 30 in 1990. In 1988, the majority of sea trout were tagged between May and June. Of the tagged sea trout entering fresh water in 1989, the majority did so between April and May. April to June was the main period for tagged sea trout entering fresh water in 1990 (Table 1).

Previous spawners dominated the sample of tagged fish in each year (Table 2); seine net catches, exploitation rates, biological characteristics and age composition are described in detail elsewhere (Mee *et al.*, 1994).

5.3 Fate of radio-tagged sea trout entering fresh water

Two (3.2%) of the 63 tagged sea trout entering fresh water over the three years left before spawning (Table 3), one in 1989 and the other in 1990.

Five (7.9%) tagged entrants were reported recaptured by rods (0 in 1988, 2 in 1989 and 3 in 1990). These recaptures came from 61 available sea trout (10 in 1988, 21 in 1989 and 30 in 1990) since two of the fish entered after the fishing season (Evans *et al.*, 1994). This therefore gives an overall fishery exploitation rate for the rods of 8.2% (0 in 1988, 9.5% in 1989 and 10% in 1990).

27 (42.9%) of the tagged sea trout went missing in-river, with the proportion ranging from 6.7% in 1990 to 90% in 1988. 69.6% of tagged entrants went missing in 1989 (**Table 3**).

Four (6.3%) sea trout were confirmed as having regurgitated their tag. Two were confirmed from rod recaptures in 1990 and the other tags were retrieved from riffles, one in 1989 and the other in 1990.

No tagged sea trout was found dead in any year.

Over the three years, 12 (19%) of the tagged entrants were deemed probable spawners (Table 3). The proportion in 1988 (10%, 1/10) was similar to that of 1989 (13%, 3/23) but less than in 1990 (27%, 8/30). Of the 12 probable spawners, two (17%) fish were recorded in the Llandovery Bran and one (8%) in each of the following tributaries: Cothi, Gwili, Sawdde, Llangadog Bran and Dryslwyn Dulais. The remaining five (42%) spawned either in the main river or in unmonitored tributaries.

As a simple measure of 'productivity', the distribution of probable spawners throughout the catchment was compared with the 'expected' distribution according to the relative area of juvenile habitat within each sub-catchment (NRA, 1994). Sample sizes prevent any firm conclusions being drawn from the data, but the observed distribution was not dissimilar to that expected. The Cothi, however, did appear to have less sea trout than expected (Table 3a).

Ten (83%) of the probable spawners were tracked moving downstream as presumed kelts, with seven (58% of probable spawners) last detected at or below the tidal limit. A further two emigrating kelts were last detected at TY3, 2.5 km above the tidal limit.

5.4 Freshwater migration patterns

Tagged sea trout demonstrated discrete patterns of behaviour in fresh water. The upstream movements were categorised into the following patterns:

(i) Discontinuous migration. Here sea trout migrated upstream stopping only intermittently for periods of less than 5 days (Fig. 4a).

(ii) 3-stage migration. Sea trout in this category exhibited an initial period of upstream migration followed by a quiescent stage (minimum stop of 5 days without a nett movement >2 km), typically located in large pools. Following quiescence the fish continued upstream, usually approaching the spawning period, without a subsequent stop of >5 days (Figs. 4b-d).

(iii) Stepped migration. This category is similar to the 3-stage migration except that the fish exhibited two or more quiescent phases, migrating upstream in discrete steps (Figs. 4e-f).

The number of sea trout displaying each pattern of behaviour was assessed from probable spawners (fish of a different fate, e.g. recaptures, were not included due to the incomplete nature of their tracks). Overall, 6 fish exhibited a 3-stage migration pattern, 2 fish a stepped migration and 2 fish a discontinuous migration. The migration patterns of the last two are unknown due to their early departure past the tracking zone (one in the Gwili and the other in the Cothi).

The pattern of migration varied in different months of the year and probably reflects the time of entry in relation to the spawning season (Fig. 5). Both the sea trout demonstrating a discontinuous migration entered during October, approaching the spawning period.

5.4.1 Quiescent stage

Considering the sea trout exhibiting quiescent behaviour, the median time between entry to freshwater and the first quiescent phase was 3.8 days (range 0.7 - 25.7 days, n=15). During this initial entry the median time of travel was 5.2 kmd^{-1} (0.58 - 15.7 kmd^{-1}).

Overall, the spatial distribution of quiescent phases demonstrated that most (60%) sea trout became quiescent in the lower river (**Fig. 6**). A further 30% of the quiescent stages were located in the middle river with the remaining 10% in the upper river. This overall pattern was not however consistent amongst years. In 1989, 8/9 quiescent stops were in the lower river with one in the middle river. In 1990, 4/10 quiescent stops were in the lower river, 4/10 in the middle river and 2/10 in the upper river.

The duration of each quiescent stop varied from 5.1 days to a maximum of 144 days, with a median of 16.5 days (**Fig. 7**).

To determine whether the location of quiescence by sea trout was linked to their final spawning destination, the location of the first quiescent phase of probable spawners was plotted against their highest recorded position (**Fig. 8**). This demonstrated a tendency for sea trout spawning higher in the catchment to migrate further before quiescing (Spearman's Rho=0.90, $P<0.01$, n=7), although fish were recorded quiescent up to 33 km below their highest recorded position.

5.4.2 Secondary migration

The secondary migration undertaken at the end of the quiescent phase took sea trout either to a subsequent quiescent stage or, in later months, to the spawning grounds. Most sea trout continued upstream from their last location of quiescence (**Figs. 4b-e**). One fish, however, undertook quiescence well into the middle river (52 km) but subsequently returned downstream some 17 km to enter the Dryslwyn Dulais around spawning time (**Fig. 4f**).

5.5 Migration rate for all sea trout

In addition to the sea trout which made quiescent stops and those that migrated straight to the spawning grounds, some limited information on the migration in fresh water was available from sea trout with different fates, e.g. unknown fate or those fish which went missing in river. The minimum distance travelled and the time taken to do so was available for all fish.

Overall, the median rate of migration between entry and becoming quiescent/last being detected moving was 0.194 kmh^{-1} (range 0.024-1.54 kmh^{-1}, n=33). This equates to a median of 4.7 kmd^{-1} (range 0.58-37 kmd^{-1})

5.6 Rod recaptures

Of the five rod recaptures over the three years, none were taken within 43 days of entry (Fig. 9). Thereafter, four out of the five recaptures were taken within the following 12 days, i.e. 43-55 days after entry. One sea trout was recaptured 80 days after entering fresh water. The majority of recaptures were taken within one calendar month, 8 June-9 July, with one sea trout recaptured in August.

Two of the five recaptures had regurgitated their tags, giving a regurgitation rate of 40%. The migratory stage during which these fish were caught is therefore unknown. Of the remaining three recaptures, one was taken during quiescence and two were last detected moving.

5.7 Time of entry and spatial location

To determine whether the date of entry by sea trout influenced the spatial distribution of spawning, the highest recorded position of probable spawners was plotted against the number of days between the 1 January (in the year of tagging) and the date of entry (Fig. 10). Although the sample size was small, there was a tendency for sea trout entering earlier in the year to spawn higher in the catchment (Spearman's Rho=-0.59, $P<0.05$, n=10).

5.8 The influence of environmental variables upon freshwater migration

5.8.1 Freshwater flow

Initial entry

Elevated freshwater flow was demonstrated to encourage entry to fresh water from the estuary (Evans, *et al.*, 1994). However, sea trout were recorded entering and undertaking large migrations in fresh water under relatively low flows. The minimum flow at which upstream migration was recorded was 3.5 $m^3 s^{-1}$ (0.1 ADF).

A sea trout entering in April migrated 60.4 km in 8.2 days (Fig. 4g; average of 7.4 kmd^{-1}), during which period the median flow experienced was 9.5 $m^3 s^{-1}$ (0.25 ADF). Another sea trout entering in May migrated 47.9 km in 11.8 days (Fig. 4h; average of 4.1 kmd^{-1}), during which period the median flow was 5.0 $m^3 s^{-1}$ (0.13 ADF).

For sea trout exhibiting a 3-stage or stepped migration, no correlation between the location of the first quiescent phase and the mean daily flow (MDF) on the day of entry was demonstrable (Spearman's Rho=0.151, $P>0.05$,n=12). Similarly, no correlation between the MDF on the day of entry and the time between entry and quiescence was demonstrable (Spearman's Rho= -0.04, n=12, $P>0.05$).

Secondary movement

Some sea trout ignored freshets during their quiescent phase (e.g. Figs 4b,e), particularly during summer months. The eventual timing of the secondary migration did, paradoxically, coincide with a defined freshet in 53% (9/16) of cases. Since defined freshets only occupied 30% of the overall study period (aggregate of April to October each year and weighted according to the sample size of fish each year), secondary movements were therefore significantly biased towards periods of freshets (Chi^2 = 4.26, df=1, $P<0.05$).

The seasonal difference in the willingness to respond to freshets was examined by identifying the number of freshets occurring each month, assessing the number of quiescent sea trout available for each freshet, and then calculating the proportion of available fish which moved (Table 4; to be available sea trout had to have been quiescent for at least five days prior to the beginning of the freshet). The small sample size prevents a statistical examination of the data, but it appears that sea trout may be more responsive to freshets in the early part of the year (April/May) and again in October, as the spawning period approaches.

To investigate whether sea trout responded to particular discharge levels *per se*, each defined freshet was categorised into a 30 $m^3 s^{-1}$ flow band, according to its peak discharge (**Table 5**). No dependency between the proportion of sea trout moving and the peak discharge rate was apparent (Table 5), although sample sizes prevented a statistical examination of the data.

Freshets were also categorised according to the relative change in flow caused by the freshet (peak flow/start flow of freshet; **Table 6**). The proportion of sea trout moving did not appear to be influenced by the quotient of the peak/start flow of a freshet, although sample sizes prevented a statistical examination of the data.

In summary, whilst elevated freshwater flow was important for migration success in the estuary (Evans, *et al.*, 1994), sea trout were recorded migrating long distances in fresh water under relatively low flows. Freshets were however important in aiding secondary migration after quiescence, particularly approaching the spawning season.

5.8.2 Diurnal movement past scanners

Overall, upstream movements past scanners in the lower river (TY2-TY7) were biased towards night-time (**Table 7**, $Chi^2 = 63.67$, df=1, $P<0.0001$). Furthermore, the distribution of movements past scanners was significantly unimodal, with a mean time of 00:40 (Rayleigh test $P<0.001$; **Table 8**).

Overall, upstream movements past scanners in the middle river (TY8-TY12) were also biased towards night-time (**Table 7**; $Chi^2 = 33.0$, df=1, $P<0.001$). The distribution of movements was also significantly unimodal, with a mean time of 01:39 (Rayleigh test $P<0.001$; **Table 8**).

Only one and four movements were recorded at the lower scanner on the

Cothi and in the upper river, respectively. The low number of movements prevents any examination of the diurnal bias in these reaches.

Since a similar pattern of behaviour was exhibited in both the lower and middle river, the movements from each reach were combined to examine any influence of freshwater flow upon the diurnal bias in migration (Table 7). At lower flows the bias towards night-time migration was particularly evident (Table 7), but at flows >20 $m^3 s^{-1}$ this bias no longer applied.

5.9 The movement of kelts

Seven of the 10 tagged kelts reached the tidal reaches of the Tywi. Some kelts were observed to emigrate the river in one virtually continuous movement (e.g. Fig. 4b,c), whilst others descended, held station for several days and then continued their emigration (e.g. Fig. 4a,d).

The overall rate of emigration varied from 0.026 kmh^{-1} to 3.35 kmh^{-1}, with a median of 0.23 kmh^{-1} (5.5 kmd^{-1}). Freshwater flow appeared to be important since all but one of the kelts initiated emigration during a freshet.

The rate at which kelts passed between scanners (V_k) was compared with the expected velocity (V_e) at the flows prevailing (NRA unpub., time of travel from dye tracing experiments). This enabled an assessment of whether kelts emigrated passively with residual flow or exhibited active emigration. 18 detections between scanners were recorded (from 6 fish) and V_k was $>V_e$ by a factor of 1.5 or more (1.52 to 2.47) on six occasions, suggesting active emigration is exhibited by some fish (Table 9). For five of the 18 movements V_k was not dissimilar to V_e ($0.5xV_e < V_k < 1.5xV_e$). V_k was less than V_e on seven occasions, probably due to sea trout resting periodically between the two scanners.

The downstream movements of kelts were biased towards night-time ($Chi^2 = 5.16$, $P<0.025$, $n=18$, Table 10), with only two out of 18 movements past scanners recorded during the day.

6. Discussion

6.1 Fate of freshwater entrants

Two (3.2%) freshwater entrants left before spawning and therefore it could be argued that this is the level of 'foreign' fish entering the Tywi. However, it is not known whether these fish were non-natives since they were not detected in any other catchment and it cannot be excluded that they may have tried to re-enter the Tywi but failed.

A number of possible explanations exist to explain the in-river disappearance of 42.9% (27 fish) of tagged entrants. These include; tag failure or undetected departure from the tracking zone, illegal exploitation or undeclared legal exploitation.

Three disappearances can be explained by tag failure due to progressive loss of signal strength or malfunction. In addition, the loss of a further three tags can probably be explained by tag failure due to battery exhaustion, since they had been operational for upwards of 16 weeks; tag failure experiments demonstrated a low level of tag failure (4-8%) before 16 weeks, thereafter tags failed progressively due to battery exhaustion (Mee & Clarke, 1992).

Two fish were last detected moving and are believed to have migrated beyond the tracking zone, one in the Cothi and the other in the upper reaches of the main river.

The remaining 19 disappearances are less easily explained. Their undetected return to sea is an unlikely explanation since most fish would have had to miss upwards of five scanners to do so. Regurgitation of the tag and subsequent tag failure due to physical damage is also an unlikely explanation, since the artificial tag regurgitation experiment demonstrated that the majority of tags remained stationary, were detectable to the end of the tracking period and were not therefore damaged in the riverine environment.

The two remaining explanations for the in-river disappearance of 19 tags are illegal exploitation or undeclared legal exploitation. Two of the missing tags were detected after removal from the river. One radio-rag was returned to the Authority by an ornithologist, from a sea-gull nest on Cardigan Island. A possible explanation for the movements of this tag is that the fish was removed from the river, either by rod or illegally, its viscera (along with the tag) was discarded and taken to a refuse tip, where the sea-gull ingested the tag. Another sea trout was suspected of having been taken from the river, probably by an angler, since it was detected at TY5 (Nantgaredig bridge) only six hours after being detected by an active boat track (at 09:35) some 30 km upstream. For the fish to have emigrated on its own it would have had to have missed five scanners on the way and travelled at an average of 5 kmh^{-1}. The more likely explanation is that the fish was taken from the river and that it fired the scanner as it was being transported past Nantgaredig bridge.

Whilst it is probable that a proportion of the disappearances are explained by factors discussed above, no satisfactory alternatives to illegal take/undeclared legal take exist to explain the majority of fish deemed lost in fresh water.

15 (23.8%) of the freshwater entrants had an unknown fate. These fish could have either regurgitated the tag and continued migrating (four others confirmed as this), or died *in situ*. Their ultimate fate is important since if they regurgitated the tag and continued migrating, the proportion of probable spawners may have increased by 23.8%. It is unlikely that 23.8% represents the natural rate of mortality in fresh water, since many of the carcasses would be found by anglers and reported to the Authority. The 'tracks' of the artificially regurgitated tags were similar to the tracks of sea trout classified as having an unknown fate, therefore it is probable that many of the sea trout of unknown fate had regurgitated their tag. Tag regurgitation was high in rod recaptures (40%) and has been found a problem in other studies of sea trout (Solomon & Storeton-West, 1983).

Only 19% of entrants were classified as probable spawners. If the sea trout categorised as (1) having an unknown fate (2) known regurgitation due to tag retrieval and (3) Probable tag failure are added, this would increase the proportion of probable spawners to ca. 60%.

6.2. Season of return

The temporal variation in the run timing of the different stock components is given elsewhere (Mee *et al.*, 1994). Previous spawners form an early spring run in April/May, along with older maidens (April-June). From June onwards whitling (.+ sea trout) appear in the catches and dominate the entrants until September. A late run (October-December) of larger sea trout was recorded but many of these fish may be delayed spring migrants (e.g. **Fig.** 4**a,c**).

Entry to fresh water in the spring results in some sea trout doing so up to eight months before spawning. Why they should enter so early is unclear. It is unlikely that on the Tywi they do so because they require more time to migrate, since sea trout entering in October were able to ascend to the most upper part of the catchment (**Fig.** 4**c**).

The success of entry through the estuary increased with increasing flow (Evans *et al.*, 1994) and therefore returning during the spring or early autumn may increase the likelihood of sea trout experiencing flows conducive for migration into fresh water. The return of the whitling component during the summer, when flows would be expected to be at their lowest, may simply be a function of the time between smolt emigration (spring) and the minimum time required for sea feeding.

Sea trout kelts were recorded emigrating back to the estuary in November/December. For these fish to return in the following April/May, they have only 5-6 months in which to regain condition and develop energy reserves for the following year. The length increments recorded from sea trout on the Tywi (Mee *et al.*, 1994) suggest that kelts from this river experience favourable conditions for reconditioning and growth, e.g. a 590 mm (ca. 5.5 lb) female sea trout tagged on the spawning beds on the 5 November 1992 (Evans, 1994b), was recaptured on the 5 May the following year by a coracle. On recapture the fish measured 690 mm and weighed 8 lb.

The marine migrations of sea trout are still largely unclear. It is therefore unknown what effect the marine migration has upon the season of return of previous spawners or the other stock components.

6.3 Freshwater migration

The different patterns of sea trout migration in fresh water can be assessed in relation to their ultimate reason for entering, i.e. spawning. On the Tywi this takes place between late October and December (Evans, 1994b), and thus it is understandable that sea trout entering in later months migrate immediately to the spawning areas. For sea trout migrating during the spring a period of 'waiting' is required, corresponding to the quiescent behaviour of these fish. The period spent in quiescence is therefore likely to be a function of the date between entering and spawning.

The patterns of migration recorded for sea trout are similar to those for salmon (Milner, 1990; Evans *et al.*, 1994b), with initial entry followed by periods of quiescence and a subsequent secondary migration.

Sea trout movements in the lower and middle river were biased towards night-time when freshwater flow was less than 20 $m^3 s^{-1}$ (<0.5 ADF). No such bias was evident at higher discharges, with movements distributed throughout the day. This suggests a preference for migrating under lower light intensity, as has been suggested for salmon (Milner loc. cit.; Evans *et al.*, 1994b), and is an extension of the behaviour displayed by sea trout in the estuary (Evans *et al.*, 1994).

The location of quiescent stops differed between 1989 and 1990, with six out of 10 stops in the middle and upper river in 1990 compared with one out of nine in 1989. The reason for this difference is unclear. No relationship was observed between river flow and (1) the location at which sea trout first became quiescent or (2) the time between entry and quiescence.

Freshets were important in stimulating secondary movement although no preference for moving during freshets with higher flows, or those causing a different relative change in flow, was evident. The response of sea trout to freshets did appear to vary through the year, decreasing from April onwards before rising sharply again in October, approaching spawning.

It should be recognised that the description of sea trout freshwater migration given here is drawn from a relatively small number of fish and that both 1989 and 1990, when the majority of data were collected, were influenced by drought conditions.

Freshwater flow has been implicated above in modifying the freshwater behaviour of sea trout. Water temperature was not recorded during the study but increasing temperature has been implicated in reducing the upstream migration of salmon (Alabaster, 1990), though coinciding with decreasing flows. Other variables which change with flow (e.g. water velocity, turbidity, water chemistry) may also be responsible for stimulating sea trout movement. Flow is the variable most often measured and if it is a surrogate for some other influencing variable then, for the purpose of management, this does not matter as long as the relationship between flow and the other variable is constant. A constant relationship with flow may not be true for some variables, e.g. turbidity. This may have implications for the effectiveness of artificial releases which may not provide turbidity conditions similar to natural spates, particularly when considering the response to light intensity recorded during the study.

6.4 Kelts

A high proportion of probable spawners (58%) survived to emigrate as kelts. This is a sizeable proportion and coupled with a relatively high survival of kelts (ca. 30%; Solomon, 1994) helps to explain the longevity of the Tywi stock. Sea trout demonstrated a higher proportion of probable spawners emigrating as kelts than salmon (38%, Evans *et al*, 1994b)

Freshwater flow was again important in aiding the movement of kelts, with many fish initiating emigration during freshets. The rate of emigration was higher than expected at the prevailing flows on six out of 18 occasions, suggesting active emigration by sea trout. This rapid emigration may contribute to the survival of kelts back to the tidal reaches. Seven of the movements between scanners were slower than expected from constant passive drift, suggesting that these fish stopped between scanners. It is not known whether the movements between stopping were passive or active.

The availability of freshets during the post-spawning period is therefore likely to influence the subsequent survival of emigrating kelts, at least to the extent of reaching tidal waters.

6.5 Rod recaptures

None of the radio-tagged sea trout recaptured by rods were taken within 43 days of entry. This is in contrast to the results for salmon where 58% of recaptures were taken within 16 days of entry. Four of the five sea trout recaptured were taken within a calendar month (8 June-9 July). The timing of recaptures is probably explained by the pattern of fishing effort rather than an endogenous influence of sea trout. Angling effort for sea trout gradually increases through April and May, rises in June and peaks, typically, in July (Evans, 1994c). Therefore, whilst many fish may enter earlier in the year, substantial fishing effort, and the concomitant likelihood of exploitation, does not occur until June/July. In effect, therefore, the time between entry and recapture is likely to be a function of the time of entry prior to peak levels of fishing effort. These results indicate that, in contrast to salmon, sea trout remain susceptible to angling pressure for long periods after entering fresh water.

6.6 Management implications

6.6.1 Inter and intra-catchment identity

No direct evidence of non-Tywi sea trout entering the freshwater reaches of the Tywi exists. Two (3.2%) of the freshwater entrants, however, left before any likely spawning activity. It could therefore be argued that these were of non-Tywi origin, but it cannot be precluded that they were Tywi fish that failed to re-enter the river.

Even if the two fish above were of non-Tywi origin, 3.2% represents a low level of straying. This indicates that a negligible bias will be introduced into productivity estimates for the Tywi catchment from catches/counts of sea trout in the freshwater reaches of the Tywi. This low level of straying was determined predominantly from the older sea age classes. Whether the younger whitling component of the stock have a similar low level of straying could not be determined.

All except one sea trout continued upstream from its location of quiescence and therefore the downstream movements at the end of quiescence exhibited by salmon on the Tywi (Evans *et al.*, 1994b) were not repeated by sea trout. If the lack of oscillatory movement by the small number of sea trout in this study is typical of sea trout behaviour in general, this would imply that intra-catchment productivity estimates from mid-river traps or counters will have minimal bias from duplication in sampling or fish spawning outside that part of the catchment.

Some sea trout exhibited quiescence up to 33 km below the eventual location of spawning. Therefore, assessing the spatial distribution of rod catches within a catchment does not necessarily indicate the intra-catchment productivity. Some sea trout destined for the upper river are only available in the lower and middle river, with the availability to anglers upstream dependant upon the timing of autumnal freshets coinciding with the fishing season. For some fish (e.g. **Fig 4e**), initiation of the secondary migration into the middle/upper river occurred only days after the end of the rod season.

6.6.2 Run timing and stock assessment

Without specific radio-tracking or counter/trap data, run timing and stock assessment is usually interpreted from net/rod catch data. The net and rod seasons are simply sampling 'windows' and will therefore only provide an assessment of sea trout entering within these periods. On the Tywi, the current net and particularly the rod season extend to cover the major run period. Sea trout entering between late October and December are not, however, able to be assessed. The extent of the late run may be influenced by flow availability earlier in the year, since a proportion of late entrants are delayed spring migrants.

Due to the high proportion of the run period covered by the net and rod seasons, annual sea trout catches may give an indication of the abundance of the extant stock. To reduce the bias in fishing effort, comparison of annual catch per unit effort (CPUE) may enable qualitative comparisons to be drawn between years. However, further knowledge of how the catchability of sea trout varies with flow and sea age classes is required to interpret annual variations in CPUE. CPUE is measured to assess changes in stock abundance and therefore infer changes in spawning stocks and egg deposition rates. Since there is a large variation in the size of sea trout on the Tywi, and egg deposition rates rely upon the size of the fish, CPUE in terms of weight (kg fish/hour) assesses changes in spawning stocks more effectively.

The long term susceptibility of sea trout to the rods indicates that temporal catch per unit effort from rods may not be a good indicator of the within-season entry of sea trout.

6.6.3 Exploitation

The exploitation rate of available fish, from reported rod recaptures, was estimated at 8.2%. However, a number of sea trout went missing in-river for which there was no clear explanation other than undeclared rod recapture or illegal take. To imply that all these missing fish were undeclared rod recaptures would result in a rod exploitation rate of 39.3%.

Radio-tracking enables an assessment of the possible loss of in-river sea trout due to illegal exploitation. However, to implicate illegal take as responsible for the missing in-river fish would suggest an alarmingly high level of poaching (30.2% of entrants), especially since the majority of disappearances were in 1988 and 1989 (40% entrants in 1988 and 56.5% in 1989).

The majority (68%) of missing in-river fish disappeared from the lower river, particularly within the reach 5 km either side of the Cothi confluence. This is an area where poaching is known to occur and therefore enforcement, as currently practised, should be concentrated within this reach during the spring/summer. A considerable proportion of sea trout (40%) became quiescent in the middle and upper river, therefore enforcement also needs to be targeted in these areas. The increased spatial distribution of sea trout on the Tywi gives rise to a requirement for a wider enforcement coverage for sea trout compared with salmon.

6.6.4 The use of artificial freshets

It must be recognised that the conclusions drawn in this study are based upon a relatively small number of fish and therefore their applicability to the population as a whole may be questioned. However, management decisions need to be based upon the best available information and this study remains the largest source of data for examining the long-term behaviour of adult sea trout in fresh water.

Sea trout appeared to be responsive to freshets in the early part of the year (April/May) but thereafter the likelihood of moving decreased through the summer, only increasing again in October, approaching the spawning period. The magnitude of the freshet did not appear to influence the likelihood of sea trout moving, therefore the influence of freshets in stimulating secondary movement may simply be dependant upon the time of the year. If so, this means that artificial releases from Llyn Brianne (maximum release 15 $m^3 s^{-1}$) may be effective in stimulating sea trout movement.

When considering the use of the water bank in Llyn Brianne for artificial releases, it must be assumed that artificial freshets will mimic the responses of sea trout recorded during natural freshets. Due to the small number of artificial releases during the study period and the simultaneous occurrence of a natural freshet with one of the releases, this assumption cannot be fully tested from this study.

During the first artificial release in this study (19-21 July 1989, peak flow of 9.7 $m^3 s^{-1}$), one of the two quiescent sea trout available responded and moved on. Neither of the single quiescent sea trout available for each of the following artificial freshets (10-14 August 1989, peak flow of 33.5 $m^3 s^{-1}$; 28 September-2 October 1989, peak flow of 28.7 $m^3 s^{-1}$) responded.

Assuming that sea trout respond to artificial freshets in the same manner as natural spates, maximising the impact upon adult sea trout, i.e. in stimulating in-river fish to move, will need to consider the temporal response of sea trout to freshets. Artificial releases during a dry spring may aid freshwater migration of sea trout but releases during late summer will be less effective. Artificial freshets may again be effectively utilised by augmenting low flow conditions during the autumn, to aid the spawning migration. Unfortunately, when planning the use of the water bank, management cannot forecast flow conditions for the year ahead. In a year with a wet autumn, holding back the use of the water bank until this period could result in it not being utilised. Occasions could occur when artificial releases would need to be used in the summer, e.g. to dilute a potential impact from pollution.

The above arguments have focused on the use of the water bank for aiding the freshwater migration of the larger adult component of the sea trout stock. The use of the water bank will also need to reflect the requirements of whitling, as yet unknown, and the best management practice for salmon (Evans *et al.*, 1994b). The definitive plan for the use of artificial releases will also need to consider the requirements of both species in the estuary (Clarke *et al.*, 1994; Evans *et al.*, 1994) and also the smolt part of the life cycle.

6.5.5 Abstraction

The current abstraction regime is discussed fully in Evans *et al.* (1994). It should be recognised that any impact of low flow by abstraction would generally be restricted to below Nantgaredig (though some impact may also be expected below Manorafon when this abstraction point is being used). Above Nantgaredig, the river discharge is artificially high when abstraction water is being compensated for by water released from Llyn Brianne.

During lower flows (<20 m^3s^{-1}), sea trout demonstrated a preference for migrating at night in the lower river. Given the predominantly night-time abstraction practised, which further reduced freshwater discharge, it is not known whether these fish were restricted in their upstream migration; sea trout may have migrated further if the flows had not been reduced at night. The sea trout tracks demonstrated that many fish migrated rapidly through the reach below the abstraction point and that the majority of sea trout (65%) undertook quiescence upstream of this location. These fish would not therefore have been affected by the diurnal variation in flow after the period of initial entry.

It is therefore likely that any effect of abstraction on sea trout migration in the Tywi is inclined to be biased towards modifying the success of migration through the estuary (Evans *et al.*, 1994).

A large proportion of fishing effort for sea trout by the rods takes place at night (Evans, 1994c). Diurnal changes in the flow pattern caused by night-time abstraction have often been quoted by anglers as being detrimental to fishing success. Daily fluctuations in river flow by night-time abstraction could therefore reduce the exploitation rate of sea trout located below the abstraction point.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 The weather during the main study years (1989/1990) resulted in most sea trout encountering drought conditions during the late spring and summer.

7.1.2 Two (3.2%) of the 63 entrants left the freshwater reaches of the Tywi before any likely spawning activity. Neither fish were located outwith the catchment and it is not therefore certain that they were non-native fish. However, if they were of non-Tywi origin, this still only results in a low level of 'foreign' fish entering the freshwater reaches of the Tywi (3.2%).

7.1.3 Five (7.9%) tagged sea trout were recaptured by rods but these recaptures came from 61 available fish, the remaining two tagged sea trout entered after the rod season. This therefore gives an overall fishery exploitation rate of 8.2% (5/61).

7.1.4 27 (42.9%) sea trout went missing in-river, the majority of which disappeared from the lower section of the river, within an area 5 km either side of the Cothi confluence. Six of these can probably be explained by tag failure whilst another two were believed to have migrated beyond the normal tracking zone. 19 disappearances are less clearly explained and probably represent undeclared capture by rods and/or illegal take.

7.1.5 12 entrants (19%) were classified as probable spawners with one fish recorded in each of the tributaries, Cothi, Gwili, Sawdde, Llangadog Bran and the Dryslwyn Dulais. Two fish were recorded in the Llandovery Bran and the remaining five spawned either in the main river or unmonitored tributaries. The small sample size prevented a rigorous comparison of the observed and expected spatial distribution of spawners. 15 (23.8%) entrants were classified as having an unknown fate. It is suggested that these probably represent sea trout which had regurgitated their tags, rather than fish which died in situ. If these fish along with the tag failures, the fish which went beyond the tracking zone and the known regurgitations are added to the 12 fish above, this raises the proportion of probable spawners to ca. 60% of freshwater entrants.

7.1.6 Freshwater entrants exhibited discrete patterns of migration. Sea trout entering during the spring summer exhibited a period of initial upstream migration followed by a quiescent period. The period of quiescence varied from 5.1 to 144 days, with some sea trout ignoring freshets during this period. Some sea trout demonstrated more than one quiescent stop, migrating upstream in discrete stages. After this holding behaviour secondary migration occurred, usually taking the fish to its spawning area in the autumn. Sea trout entering later in the year (October) were recorded migrating straight to the spawning areas, only stopping for short periods (<5 days typically).

7.1.7 Overall, the majority of sea trout (60%) exhibited quiescence in the lower river with 30% and 10% in the middle and upper river, respectively. Since some sea trout did not migrate to their final spawning destination until after the end of the rod season, some fish migrating through the middle/upper river were unavailable for capture by rods in these reaches of the river.

7.1.8 Of the five rod recaptures over the three years, none were taken within 43 days of entry. Two were taken whilst quiescent and another whilst it was believed to be undergoing upstream migration. The remaining two fish had regurgitated their tags and the migration stage at recapture was therefore unknown. This extended period between entry and recapture suggests that sea trout, unlike salmon, remain susceptible to rod recapture for many months after entering fresh water.

7.1.9 Sea trout entering earlier in the year tended to migrate further before quiescing and spawned higher in the catchment.

7.1.10 Under low flow conditions (<20 $m^3 s^{-1}$) upstream movements by sea trout in the lower and middle river were typically restricted to the hours of darkness.

7.1.11 No relationship was demonstrable between the mean daily flow (MDF) on entry and the distance migrated before becoming quiescent. Secondary movements were biased towards periods of freshets but no apparent preference was demonstrable for a certain magnitude of freshet. Sea trout did appear to demonstrate a temporal responsiveness to freshets with the likelihood of fish moving being high in April/May, decreasing through the summer and increasing again in October, as the spawning period approached.

7.1.12 10 (83%) probable spawners were recorded moving downstream as kelts, seven of which were recorded as far downstream as the tidal limit. Exrtrapolation to the underlying population suggests that 58% of kelts survive to reach tidal water. Elevated flows were considered important in aiding the emigration of kelts, with downstream movements biased towards night-time.

7.1.13 Given the preference for migrating at night, it is not known whether the predominantly night-time abstraction restricted the rate of upstream migration for fish downstream of the abstraction point, since sea trout may have migrated further if flows had not been further reduced. The sea trout tracks demonstrated that the majority of sea trout (65%) undertook quiescence upstream of the abstraction point at Nantgaredig. These fish would not therefore have been affected by the diurnal variation in flow following the period of initial entry. It is therefore likely that any effect of abstraction on sea trout migration in the Tywi is inclined to be biased towards modifying the success of migration through the estuary.

7.1.14 A large proportion of fishing effort for sea trout by the rods takes place at night. Diurnal changes in the flow pattern caused by night-time abstraction may therefore be detrimental to fishing success downstream of the point of abstraction. Daily fluctuations in river flow by night-time abstraction could therefore reduce the exploitation rate of sea trout located below the abstraction point.

7.2 RECOMMENDATIONS

7.2.1 It should be recognised that the Tywi rod fishery exploits almost exclusively sea trout of Tywi origin. Catch estimates will therefore not need adjusting before assessing productivity within the catchment.

7.2.2 The spatial exploitation of the in-season stock by rods should not necessarily be used as an indicator of intra-catchment productivity.

7.2.3 Since sea trout remain susceptible to rod recapture for long periods after entering freshwater, analysis of rod catch data as catch per unit effort (CPUE) should not be used as a measure of the within-season timing of sea trout entry.

7.2.5 The current rod (and net) season covers a large proportion of the run period of sea trout on the Tywi (March-December). Sea trout entering later in the year (October-December), which include delayed spring migrants, will not however be available for capture. Due to the high proportion of the extant stock which enters within the season, comparison of annual catch per unit effort may provide an indication of abundance/stock size.

7.2.6 It should be recognised that illegal exploitation may have accounted for a number of fish in 1988 and 1989. Given the spatial distribution of sea trout, enforcement should be concentrated within the lower river during the spring/summer. A considerable proportion of sea trout (40%) became quiescent in the middle and upper river, therefore enforcement also needs to be targeted in these areas.

7.2.7 If artificial releases are to be used for stimulating movement of adult sea trout, the temporal response of fish to freshets needs to be considered. The use of artificial releases in the summer months (July-September) is less likely to stimulate in-river sea trout to move. Artificial releases, to stimulate movement amongst in-river sea trout, would be better utilised by augmenting low flows during the spring or the autumn. A management plan for artificial releases from Llyn Brianne should also reflect the best practice for adult salmon, and the smolt stage of both species.

7.2.8 There is a need for further studies to investigate the small scale movements of sea trout above and below abstractions.

7.2.9 There is a need for further studies to investigate the freshwater movements of the younger sea age classes of sea trout. Tracking smaller fish will require suitable (smaller) radio tags and may also necessitate a different tagging methodology, e.g. peritoneal cavity tagging.

ACKNOWLEDGEMENTS

We would like to thank the following people for assistance in this work. Sally Crudgington, Tim Davies, Steve Ellery, Tony Morse and the Environmental Appraisal Unit at Penyfai house for help with fieldwork. The hydrology section, in particular Jean Frost and Rhian Phillips for providing river flow data. The seine netsmen for their assistance over the years, with a number of projects. We would also like to thank Dr. Alun Gee for his advice and support during the course of this work.

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TABLE 1 Numbers of tagged sea trout entering during 1988, 1989 and 1990.

Month	Entered 1988 No.	Entered 1988 %	Entered 1989 No.	Entered 1989 %	Entered 1990 No.	Entered 1990 %
April	0	0	4	17.4	11	36.7
May	7	70.0	15	65.2	8	26.7
June	3	30.0	0	0	6	20.0
July			1	4.4	1	3.3
August			0	0	0	0
September			0	0	0	0
October			3	13.0	4	13.3
TOTAL	10	100.0	23	100.0	30	100.0

TABLE 2. Sea age composition of tagged sea trout entering fresh water. 1+/2+ represents maiden fish, 1SM represents fish with one spawning mark (e.g. .1+SM+) and >1SM represents fish with two or more spawning marks (e.g. .1+2SM+), UR represents unreadable.

Year	1+/2+	(%)	1SM	(%)	>1SM	(%)	UR	(%)
1988	0	(0)	1	(10)	3	(30)	6	(60)
1989	2	(9)	10	(44)	7	(30)	4	(17)
1990	7	(23)	7	(23)	13	(44)	3	(10)
Overall	9	(14)	18	(29)	23	(37)	14	(22)

TABLE 3. Fate of tagged sea trout entering fresh water 1988-1990; where LBS represents left before spawning, RR represents rod recapture, MIR represents missing in-river, REG represents confirmed regurgitation, FD represents found dead, UF represents unknown fate and PS represents probable spawners.

Category	1988	1989	1990	Overall	(%)
LBS	0	1	1	2	(3.2)
RR	0	2	3	5	(7.9)
MIR	9	16	2	27	(42.9)
REG	0	1	3*	4*	(6.3)
FD	0	0	0	0	(0)
UF	0	0	15	15	(23.8)
PS	1	3	8	12	(19.0)
Tywi	[0]	[2]	[3]	[5]	
Cothi	[0]	[0]	[1]	[1]	
Gwili	[0]	[0]	[1]	[1]	
Sawdde	[0]	[0]	[1]	[1]	
Lld Bran	[1]	[0]	[1]	[2]	
Llg Bran	[0]	[1]	[0]	[1]	
Dryslwyn Dulais	[0]	[0]	[1]	[1]	
TOTAL	10	23	30	63	

* 2 of the regurgitations were confirmed from rod recaptures.

TABLE 3a. The 'expected' distribution of sea trout in the Tywi catchment according to the relative area (A) of juvenile rearing habitat within each subcatchment.

Subcatchment	A m2	%total A	Sea trout observed	Sea trout expected
Cothi	1,097,743	20.8	1	3.1
Gwili	506,100	9.6	1	1.4
Llandovery Bran	447,190	8.5	2	1.3
Sawdde	259,850	4.9	1	0.7
Llangadog Bran	157,915	3.0	1	0.5
Dryslwyn Dulais	83,650	1.6	1	0.2
Tywi excl. above	2,718,163	51.6	5	6.2

TABLE 4 Seasonal effect (1988-1990) of freshets on secondary migration of tagged sea trout. Sample sizes prevent a statistical test of any dependency between the proportion of fish moving and the time of year.

Month	No. freshets	sea trout moving	sea trout not moving	Percentage moving
Apr/May	13	2	0	100%
Jun/July	12	2	8	20%
Aug/Sep	18	1	16	6%
October	12	4	1	80%

TABLE 5 The effect of peak discharge rates of freshets upon secondary migration of tagged sea trout. Sample sizes prevent a statistical test of any dependency between the proportion of fish moving and the peak discharge of freshets.

Flow band m^3s^{-1}	No. freshets	sea trout moving	sea trout not moving	Percentage moving
0 - 30	12	4	9	30.8%
30 - 60	4	1	3	25.0%
60 - 90	7	1	6	14.3%
90 -120	8	3	5	37.5%
120 - 150+	4	0	4	0.0%

TABLE 6 The effect of the relative change of flow (peak flow/start flow) during freshets on secondary migration of tagged sea trout. Sample sizes prevent a statistical test of any dependency between the proportion of fish moving and the quotient of peak/start flow of the freshet.

Quotient: peak/start flow	No. freshets	sea trout moving	sea trout not moving	Percentage moving
Overall				
1-1.99	8	2	7	22.2%
2-2.99	10	4	6	40.0%
3-3.99	8	1	7	12.5%
4-4.99	4	2	2	50.0%
>=5	5	0	5	0.0%

TABLE 7 Diurnal periodicity of upstream movements past scanners by sea trout. The number of observed (OBS) day and night movements are compared with movements predicted (PRE) from the cumulative ratio of the day and night hours on the day of movements. Significance taken as P<0.05.

LOCATION	OBS. DAY	OBS. NIGHT	PRE. DAY	PRE. NIGHT	Chi2	df	P
Lower river	48	118	98.5	67.5	63.67	1	P<0.001
Middle river	8	41	27.9	21.1	33.90	1	P<0.001
Tywi overall	57	163	129.3	90.7	98.00	1	P<0.001
0- 5 m3s-1	3	22	16.9	8.1	35.30	1	P<0.001
5-10 m3s-1	19	61	49.3	30.7	48.53	1	P<0.001
10-15 m3s-1	13	41	33.1	20.9	31.54	1	P<0.001
15-20 m3s-1	6	15	11.4	9.6	5.59	1	P<0.050
20-30 m3s-1	5	3	4.4	3.6	n<5		
>20 m3s-1	16	24	18.7	21.3	0.73	1	NS(P>.5)

TABLE 8 Results of the Rayleigh test (Batschelet, 1981) to test for the unimodal distribution of upstream movements in relation to the time of day (Significance was taken as P<0.05).

Scanner	r	n	P	Mean time
Lower river	0.382	166	<0.001	00:40
Middle river	0.643	49	<0.001	01:39
Tywi overall	0.443	220	<0.001	00:55
Tywi <20 m3s-1	0.522	180	<0.001	01:02
Tywi >20 m3s-1	0.112	40	NS (>0.560)	

TABLE 9 Time of travel for sea trout kelts

TAG	SCANNER	TIME	SCANNER	TIME	DISTANCE km	VELOCITY km/h	FLOW PERCENTILE	EXPECTED VELOCITY	Vk/Ve
22RD9	TY11	28-NOV-90 02:10	TY10	28-NOV-90 03:05	3.3	3.60	32	2.29	1.572
22RD9	TY10	28-NOV-90 03:20	TY9	29-NOV-90 17:30	7.1	0.19	33	1.91	0.097
22RD9	TY9	29-NOV-90 17:45	TY8	01-DEC-90 18:50	4.7	0.10	40	1.64	0.058
22RD9	TY8	01-DEC-90 18:55	TY6	02-DEC-90 07:25	14.5	1.16	47	1.43	0.811
22RD9	TY6	02-DEC-90 11:50	TY5	05-DEC-90 03:05	1.7	0.03	50	0.79	0.034
23CC4	TY7	13-DEC-89 19:05	TY6	13-DEC-89 21:55	6.9	2.44	29	1.89	1.289
23GD2	LB	16-NOV-90 18:20	TY9	17-NOV-90 18:10	24.7	1.04	37	2.32	0.447
23GD2	TY9	17-NOV-90 18:15	TY8	17-NOV-90 19:10	4.7	5.13	32	2.08	2.465
23GD2	TY8	17-NOV-90 19:15	TY7	17-NOV-90 21:45	7.6	3.04	29	1.99	1.525
23GD2	TY7	17-NOV-90 21:50	TY6	17-NOV-90 23:50	6.9	3.45	27	1.99	1.732
23GD2	TY6	17-NOV-90 23:35	TY5	18-NOV-90 00:05	1.7	3.40	27	1.99	1.707
25RC7	TY7	20-OCT-89 13:40	TY6	20-OCT-89 18:25	6.9	1.45	25	2.10	0.692
25RC7	TY6	20-OCT-89 18:40	TY5	20-OCT-89 19:15	1.7	2.91	26	2.04	1.429
29BD2	TY9	14-NOV-90 00:35	TY8	14-NOV-90 02:00	4.7	3.32	35	1.89	1.756
29BD2	TY8	14-NOV-90 02:05	TY7	14-NOV-90 05:10	7.6	2.46	31	1.91	1.291
29BD2	TY7	14-NOV-90 05:20	TY6	14-NOV-90 13:10	6.9	0.88	24	2.15	0.410
29BD2	TY6	14-NOV-90 13:30	TY5	14-NOV-90 15:25	1.7	0.89	25	2.10	0.422
30DD2	TY16	31-OCT-90 00:00	TY10	02-NOV-90 23:50	24.5	0.34	26	3.06	0.111

TABLE 10 Diurnal periodicity of downstream movements past scanners by sea trout kelts. The number of observed (OBS) day and night movements are compared with movements predicted (PRE) from the cumulative ratio of the day and night hours on the day of movements. Significance taken as $P<0.05$.

All scanners	OBS. DAY	OBS. NIGHT	PRE. DAY	PRE. NIGHT	Chi2	df	P
Overall	2	16	6.65	11.35	5.16	1	<0.025

FIG. 1 THE TYWI CATCHMENT

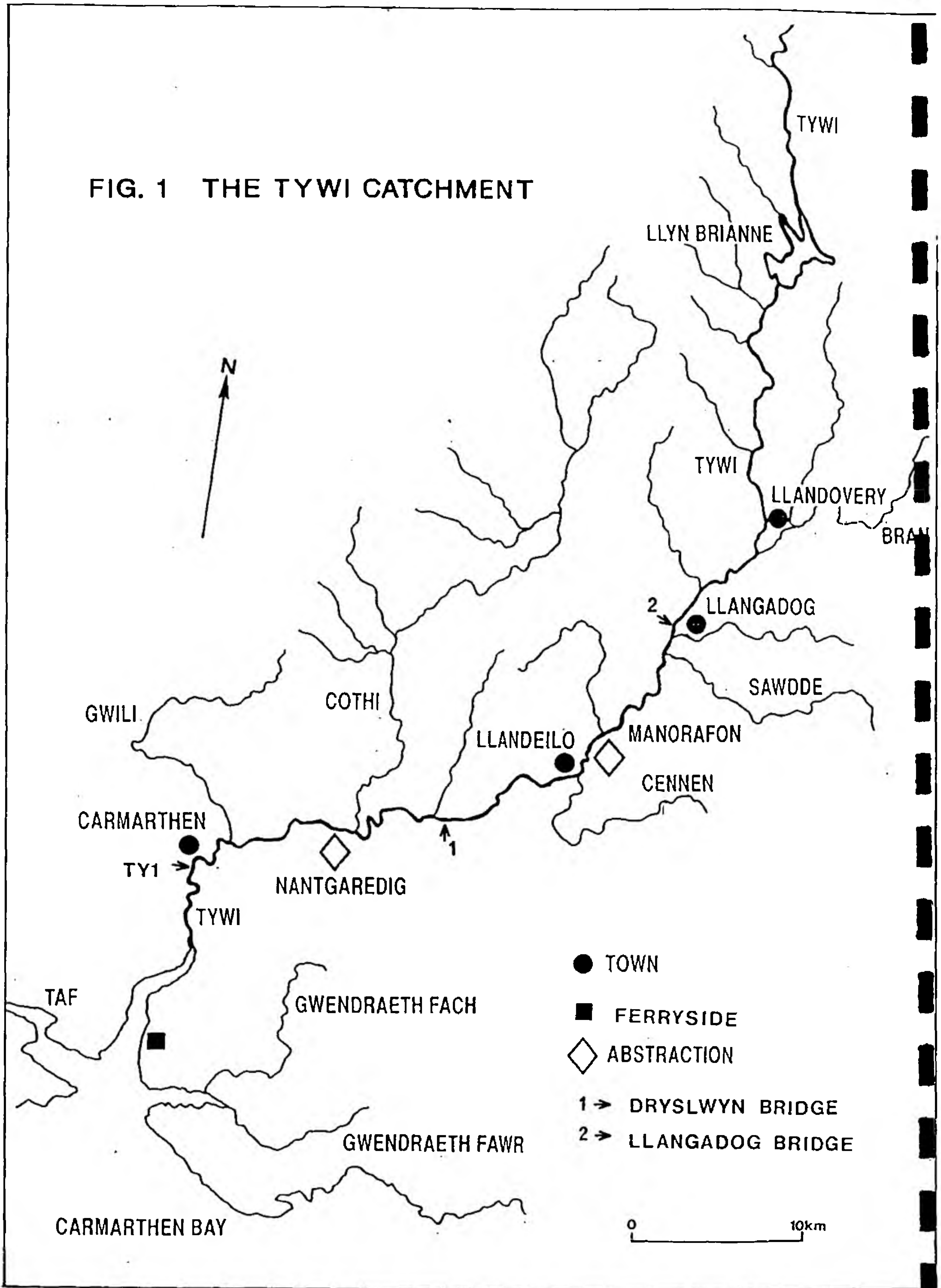

FIG. 2 SCANNER LOCATIONS

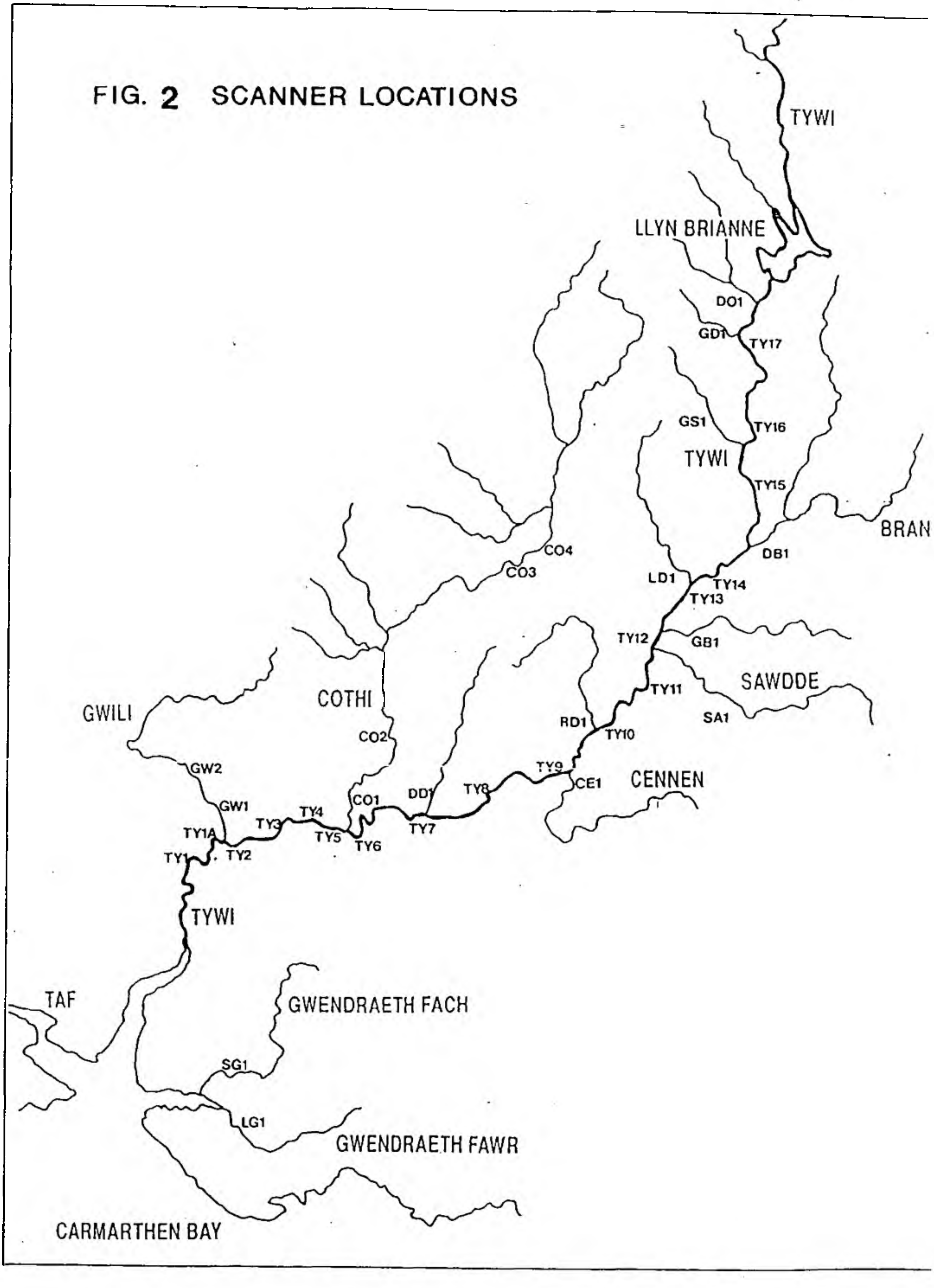

Fig. 3 Mean daily flow at Nantgaredig, 1988-1990

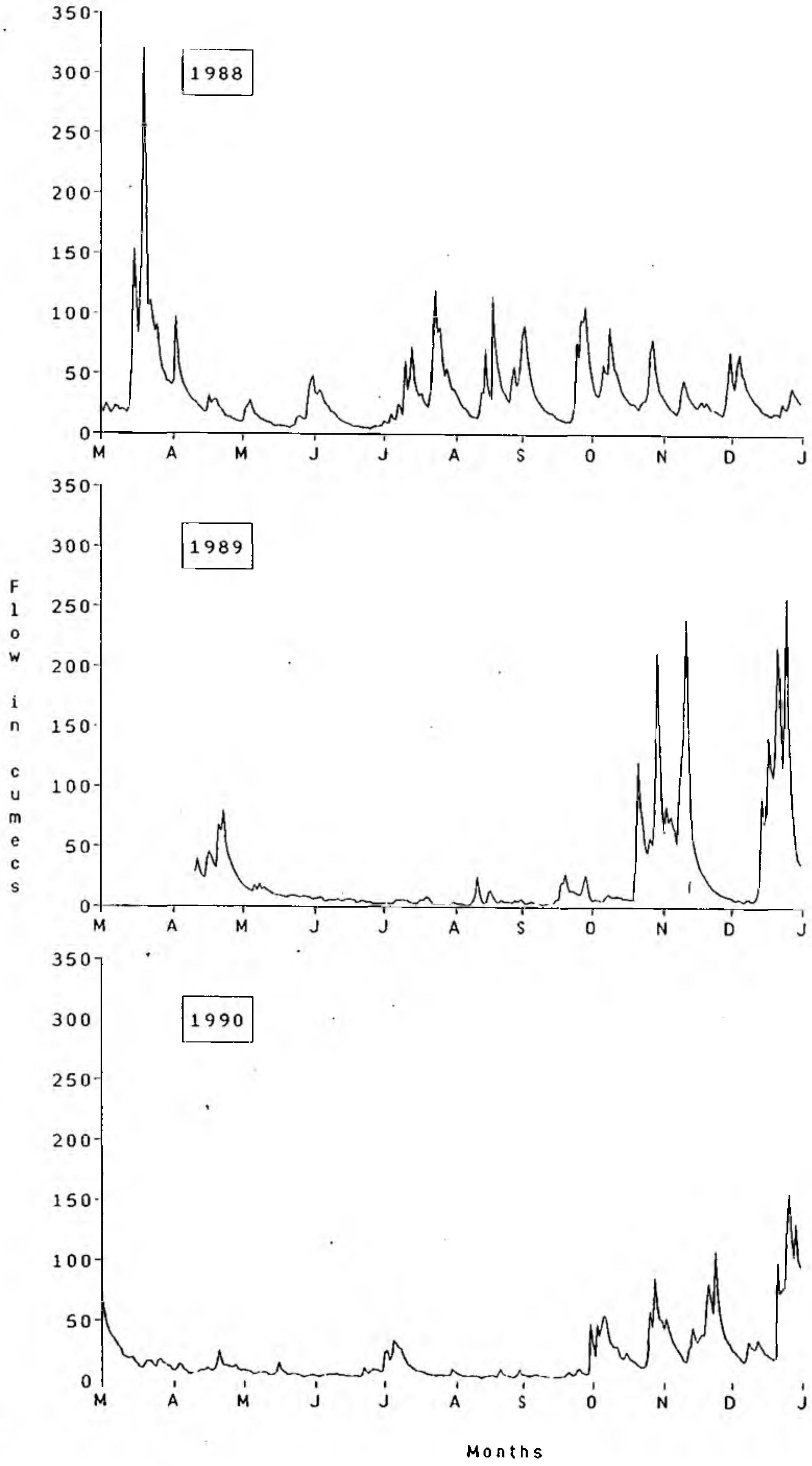

Fig 4a Female Sea trout Length : 645 mm Sea age : 1+SM+
Tagging site : NO 9 Tag : 23CC4

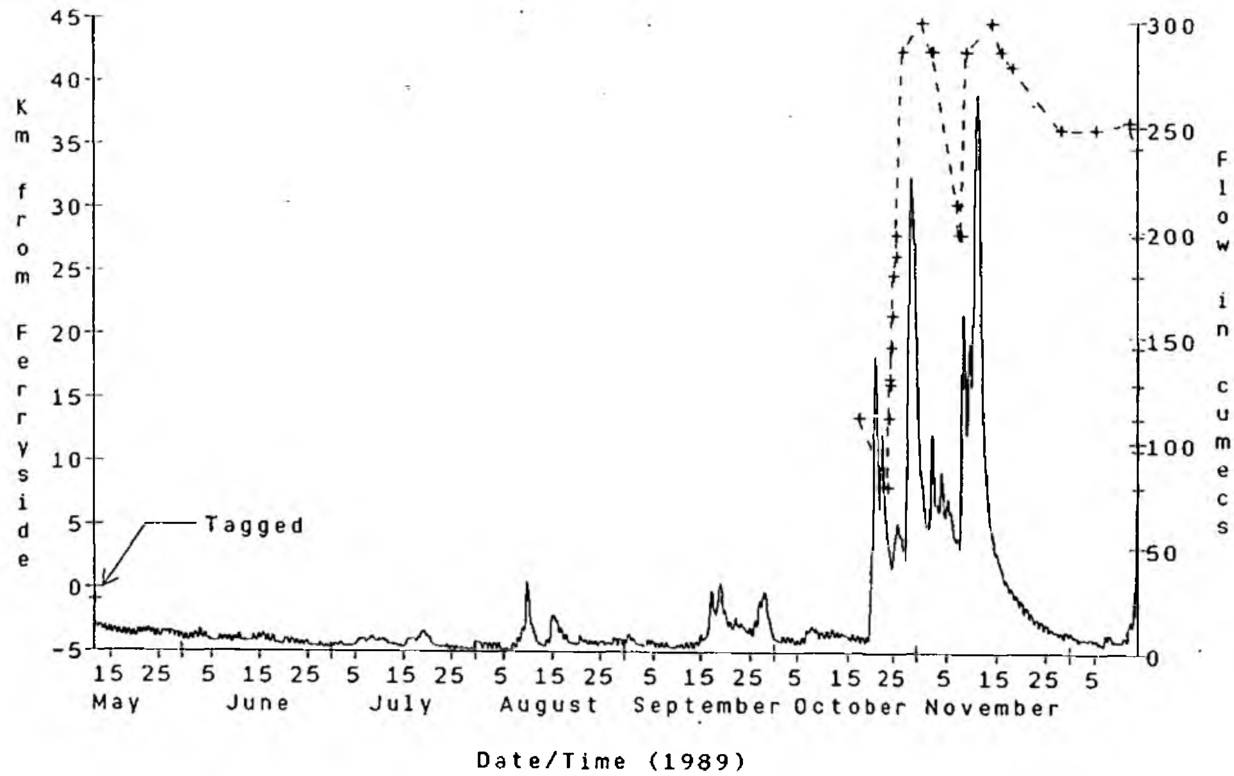

Fig. 4b Male Sea trout Length : 780 mm Sea age : 1+4SM+
Tagging site : Cystanog trap Tag : 30EB4

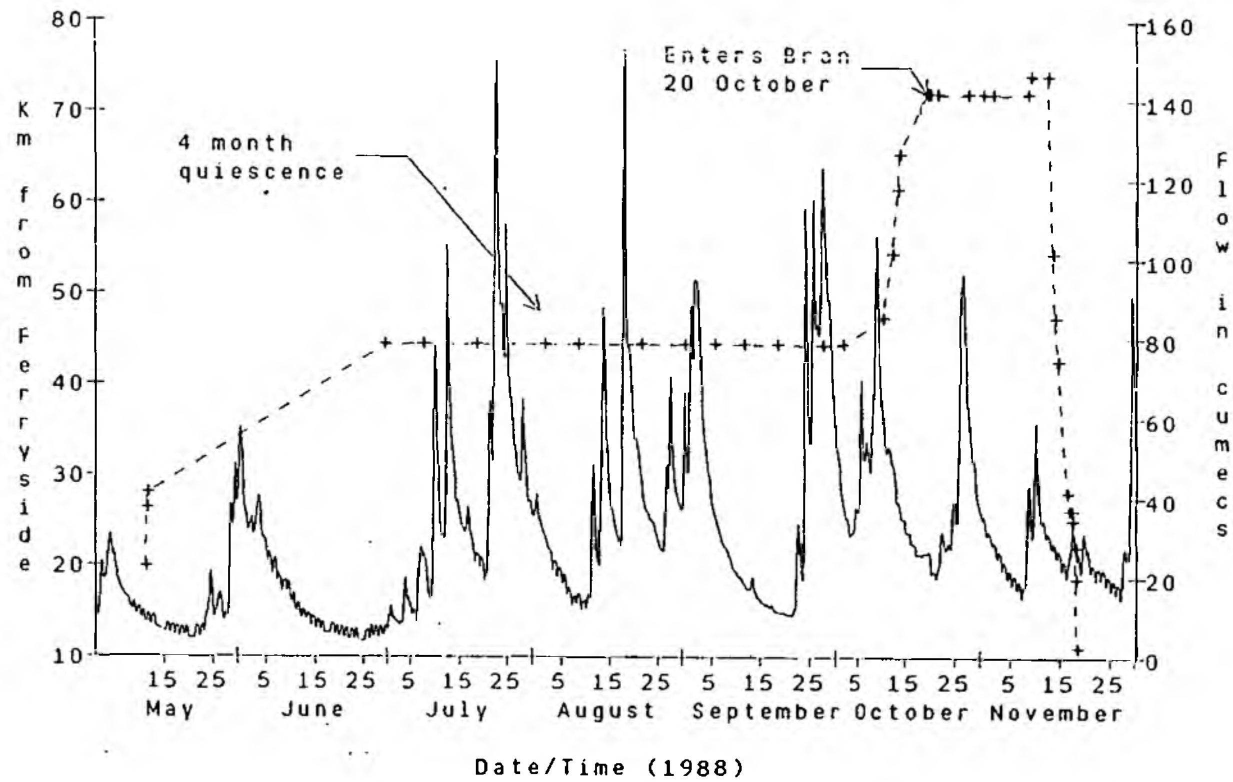

Fig. 4c Male Sea trout Length : 615 mm Sea age : 2+
Tagging site : CEFN SIDAN Tag : 23GD2

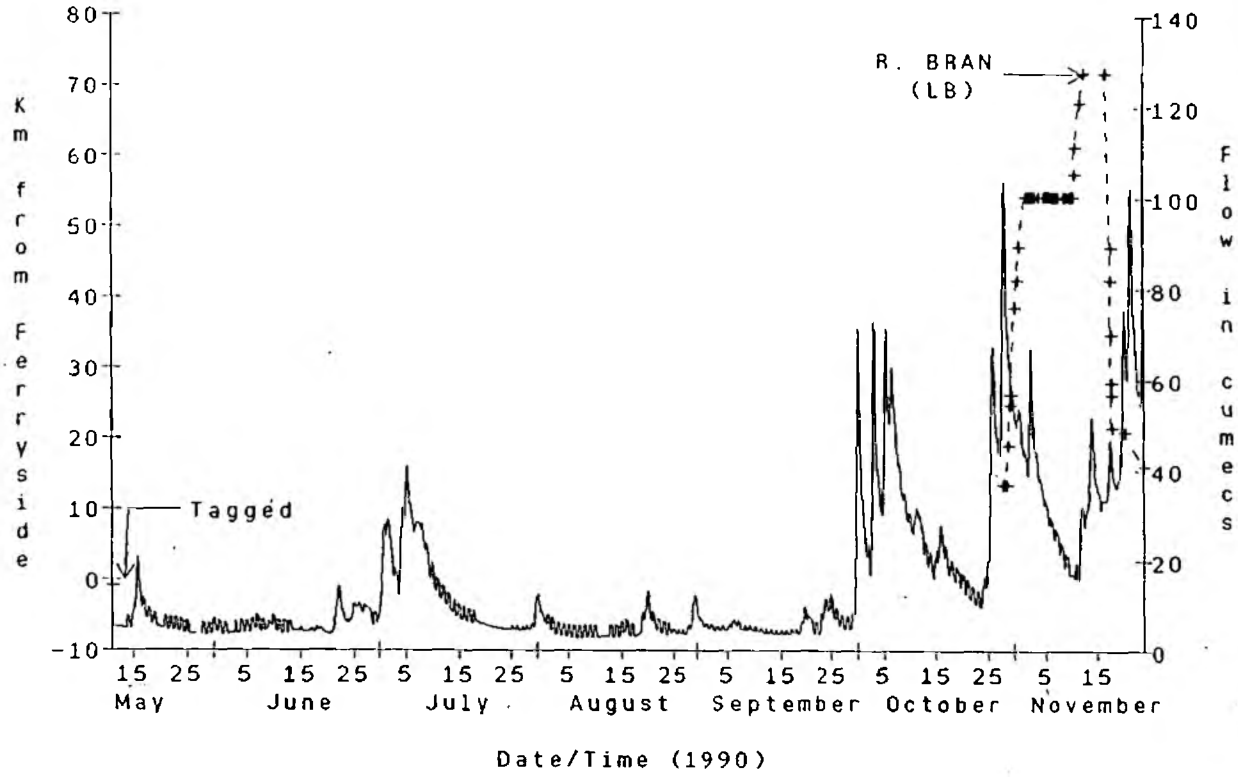

Fig. 4d Female Sea trout Length : 620 mm Sea age : 2+
Tagging site : EBWR Tag : 22RD9

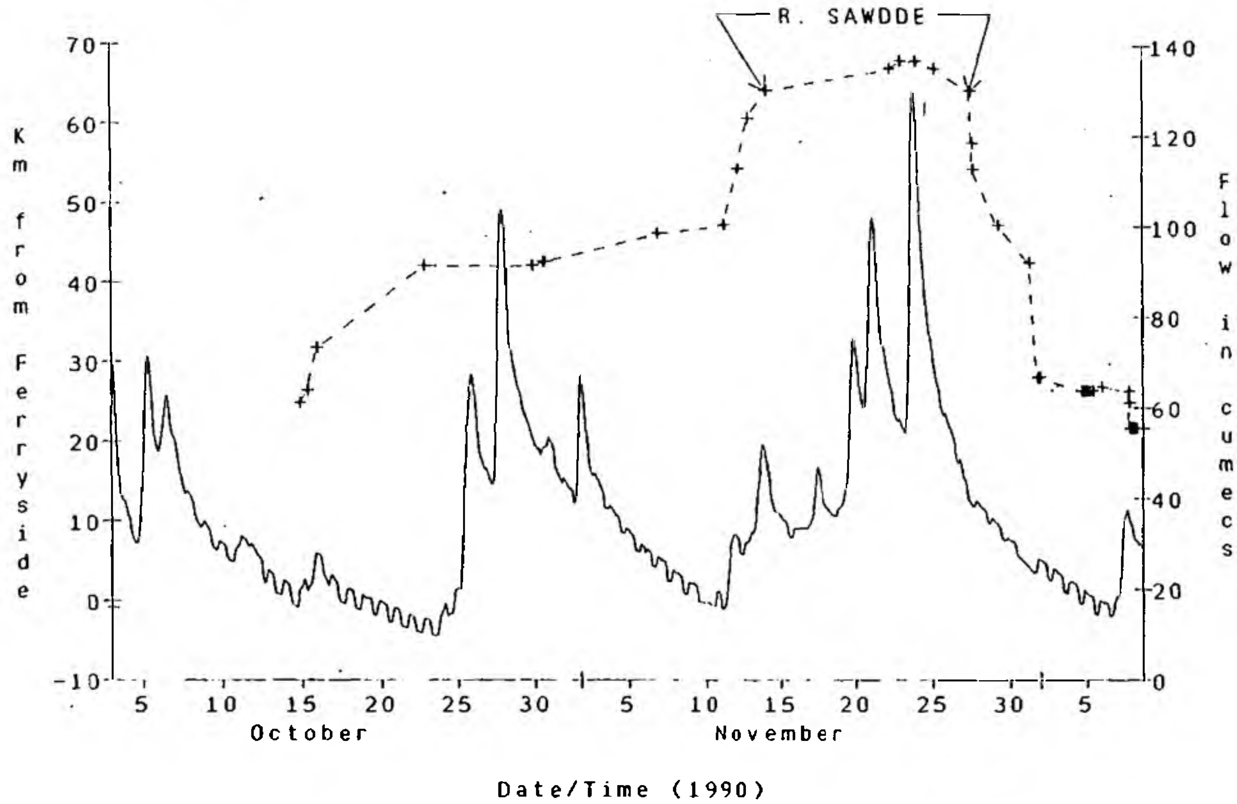

Fig. 4e Female Sea trout Length : 625 mm Sea age : 1+SM+
Tagging site : NO 9 Tag : 22FC1

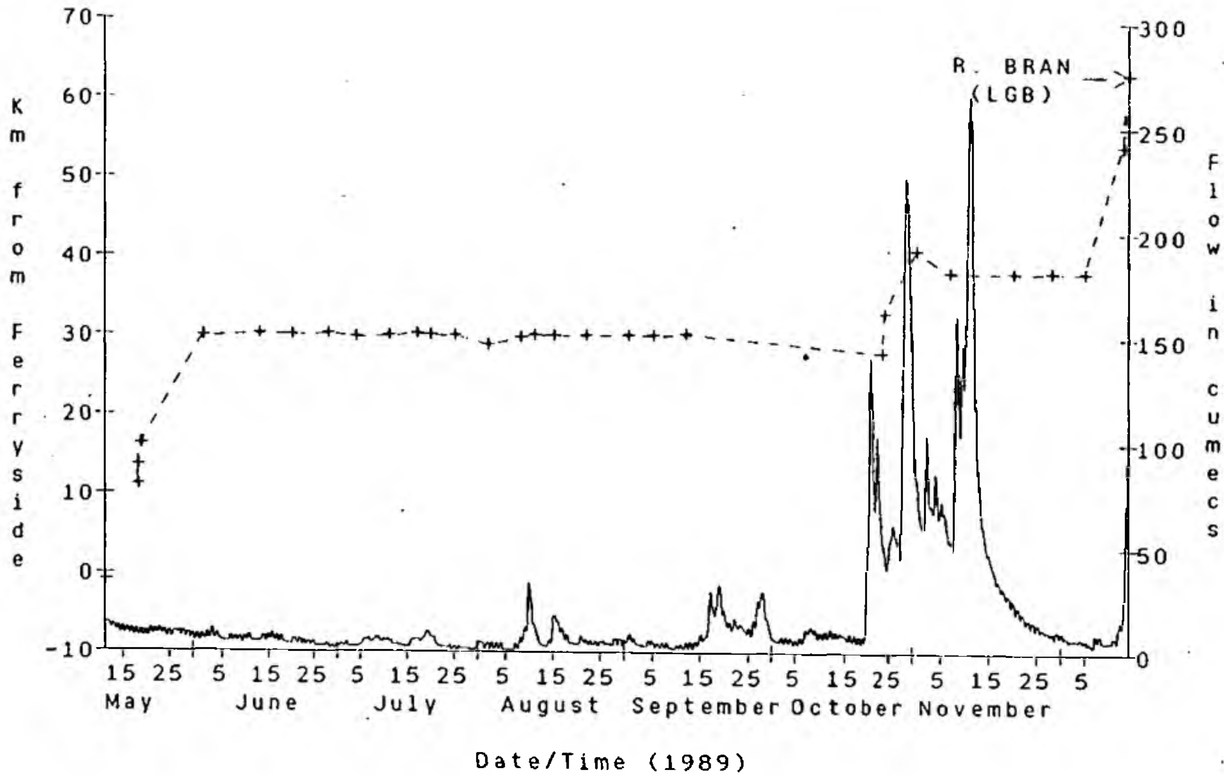

Fig. 4f Female Sea trout Length : 600 mm Sea age : 1+2SM+
Tagging site : CEFN SIDAN Tag : 29BD2

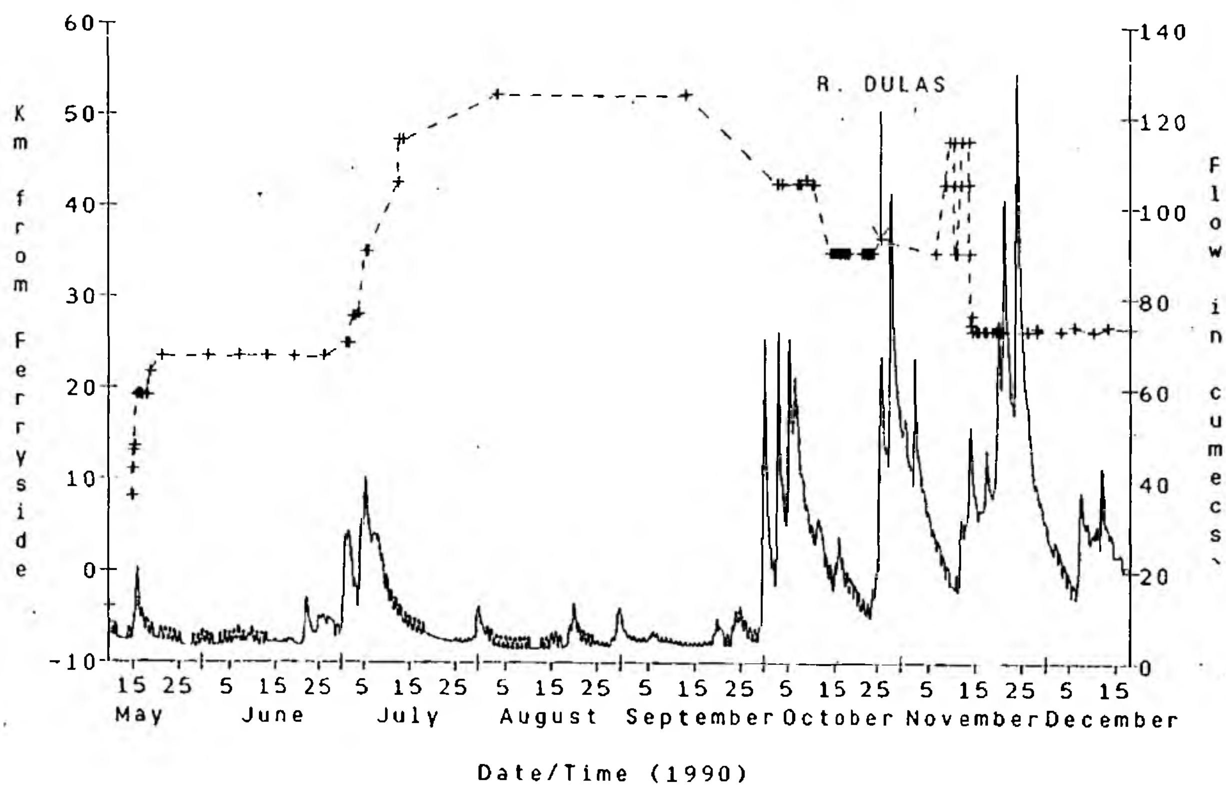

Fig. 4g Female Sea trout Length : 740 mm Sea age : 1+4SM+
Tagging site : EBWR Tag : 30DD2

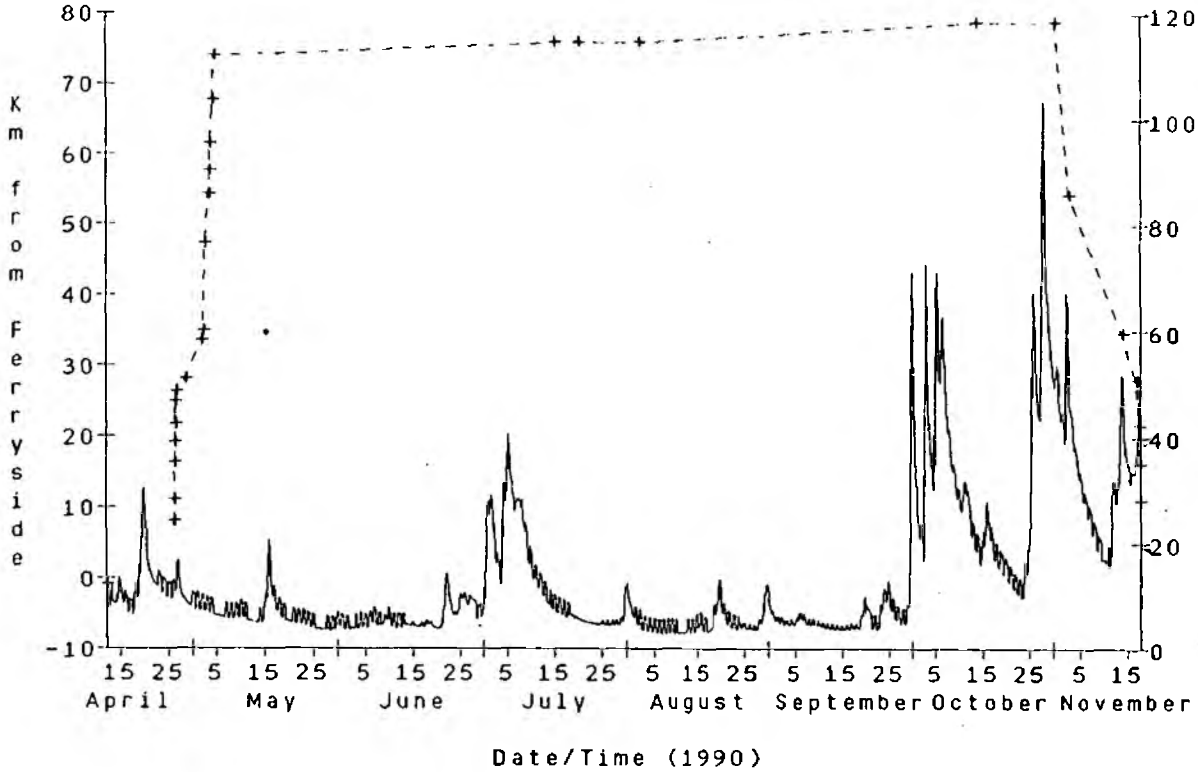

Fig. 4h Female Sea trout Length : 550 mm Sea age : 1+
Tagging site : EBWR Tag : 223FD2

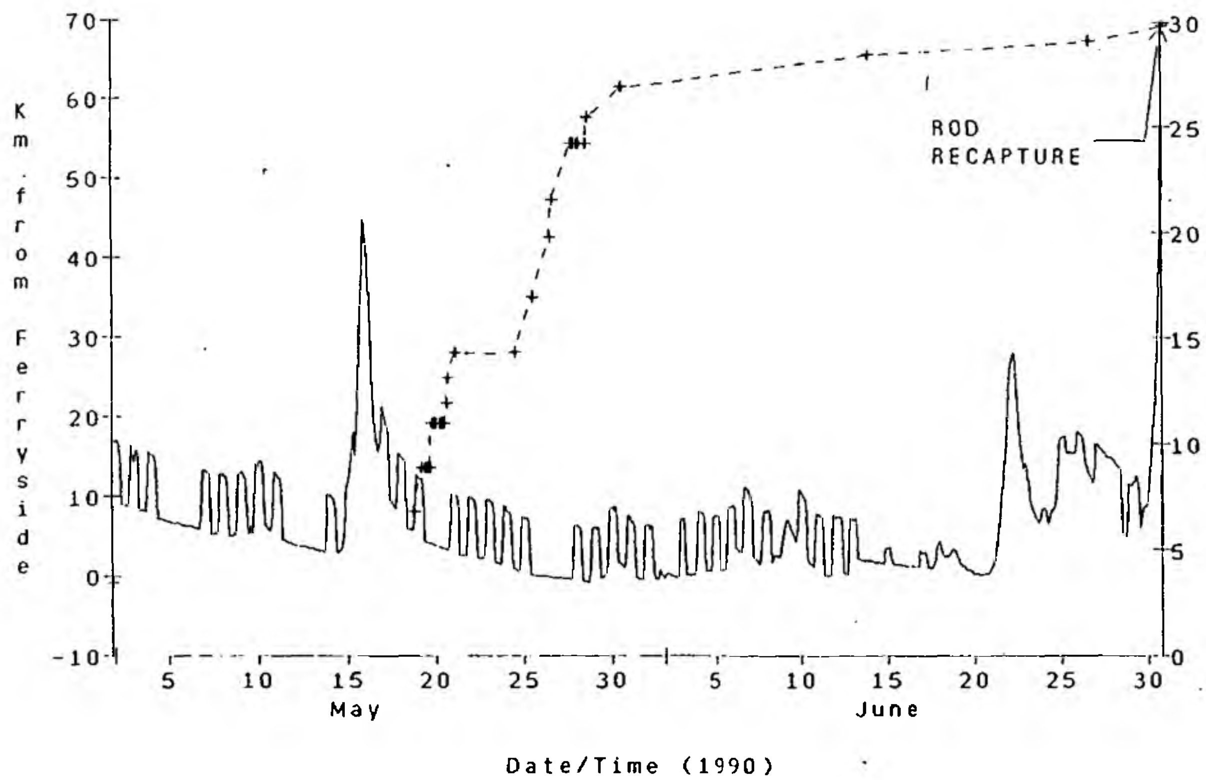

Fig. 5 Migration pattern of sea trout entering the Tywi

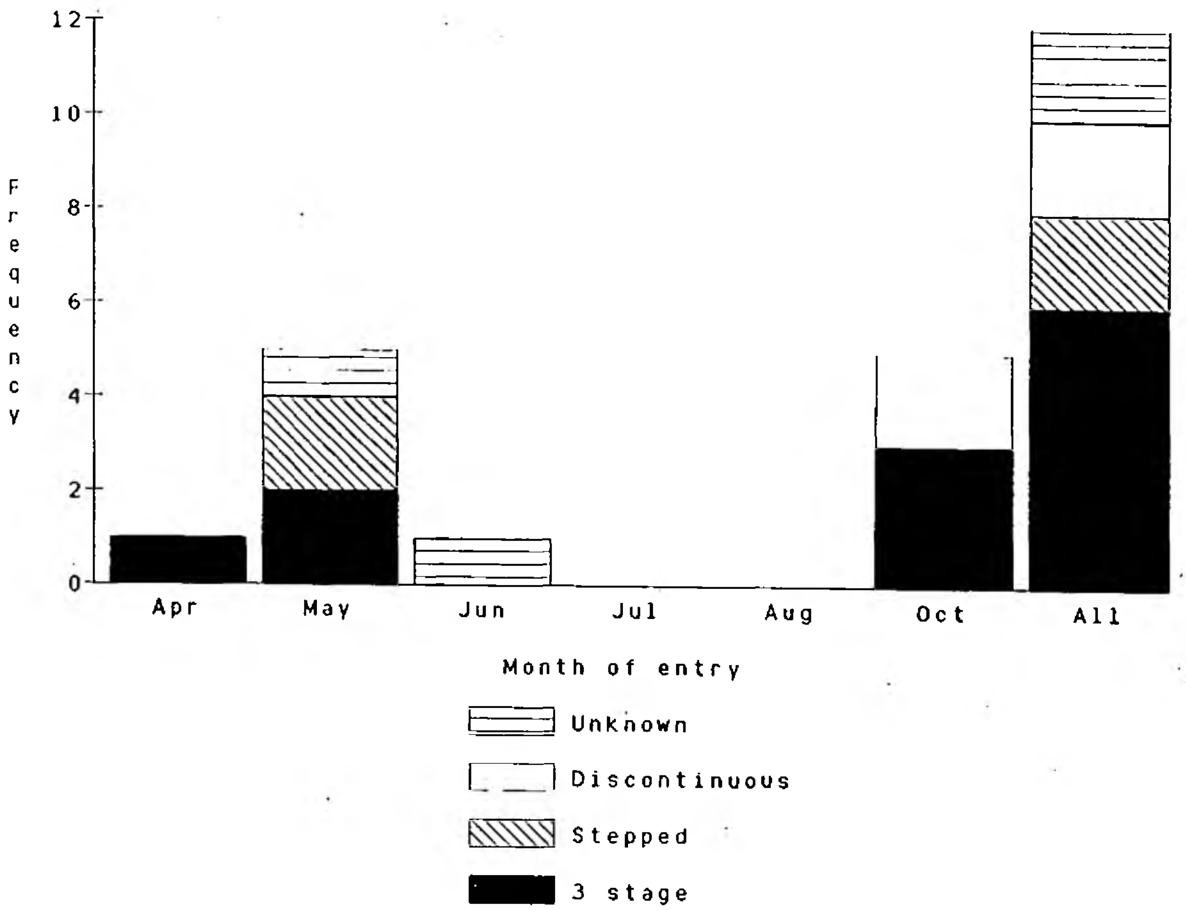

Fig. 6 Spatial location of quiescent stops (>5 days)

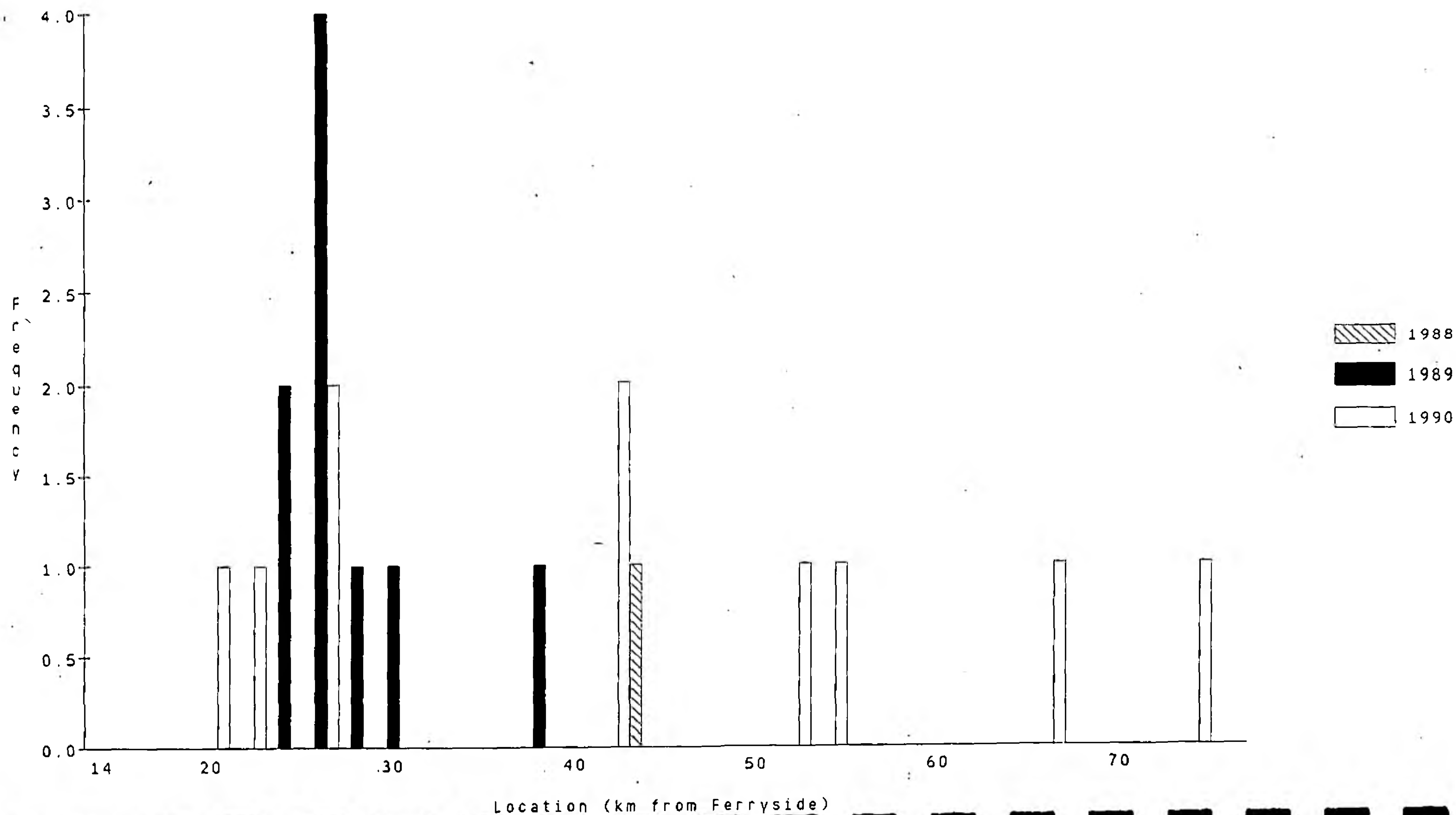

Fig. 7 Distribution of time spent in quiescence (>5 days) by sea trout

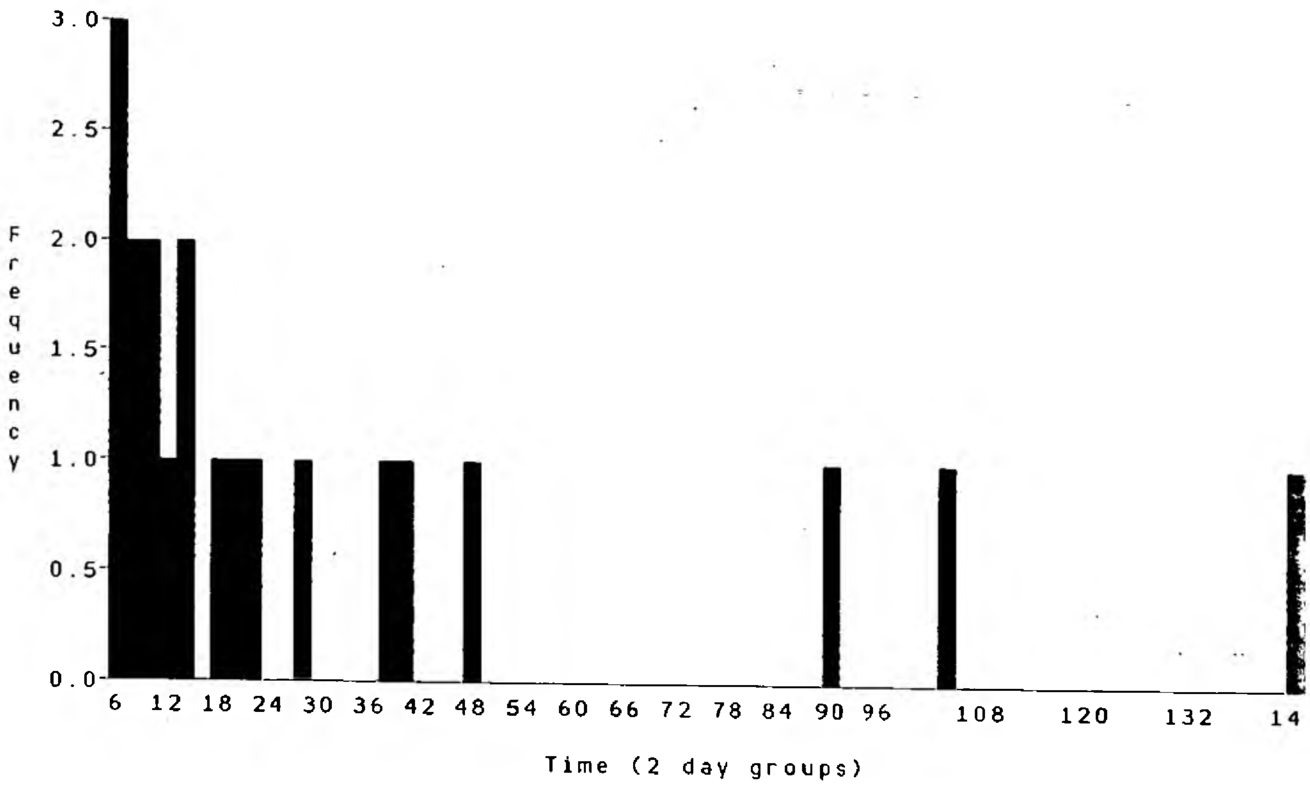

Fig. 8 Highest recorded position of probable spawners against the location of their first quiescent stop

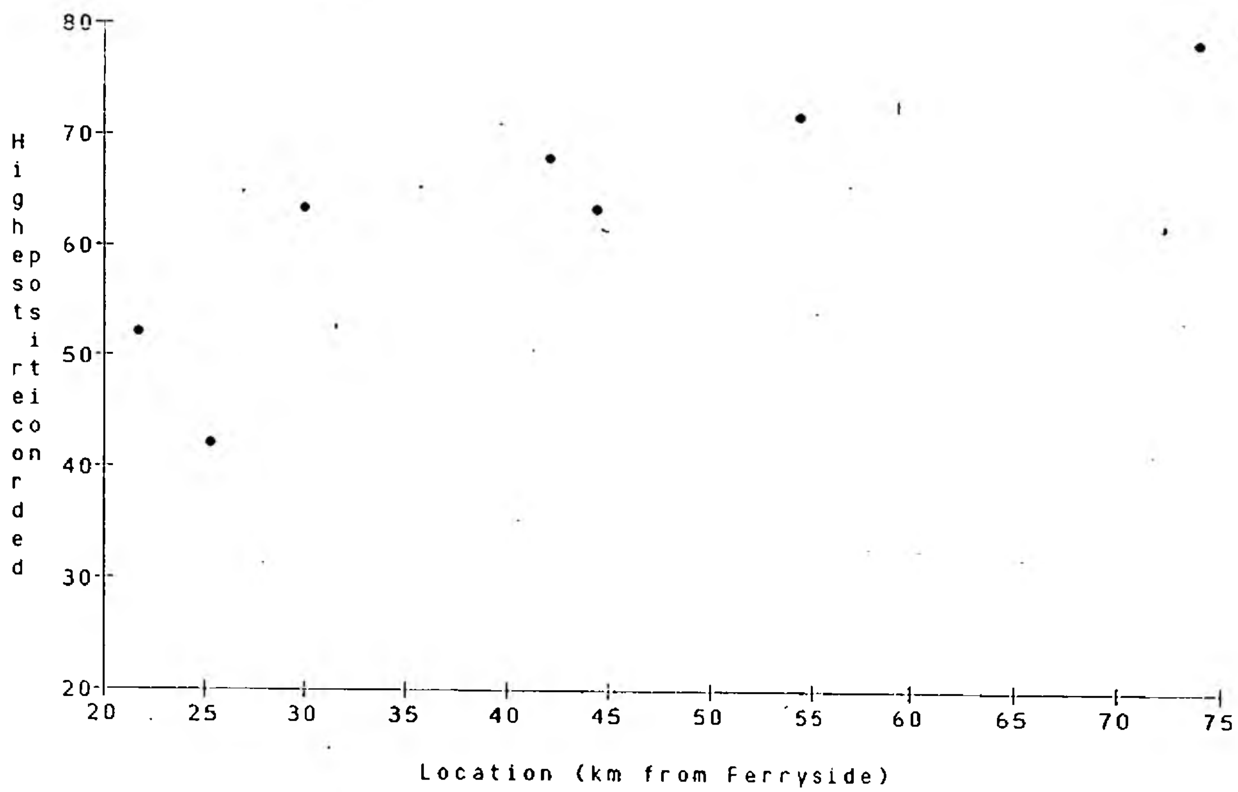

Fig. 9 Cumulative distribution of time (days) between entry and recapture

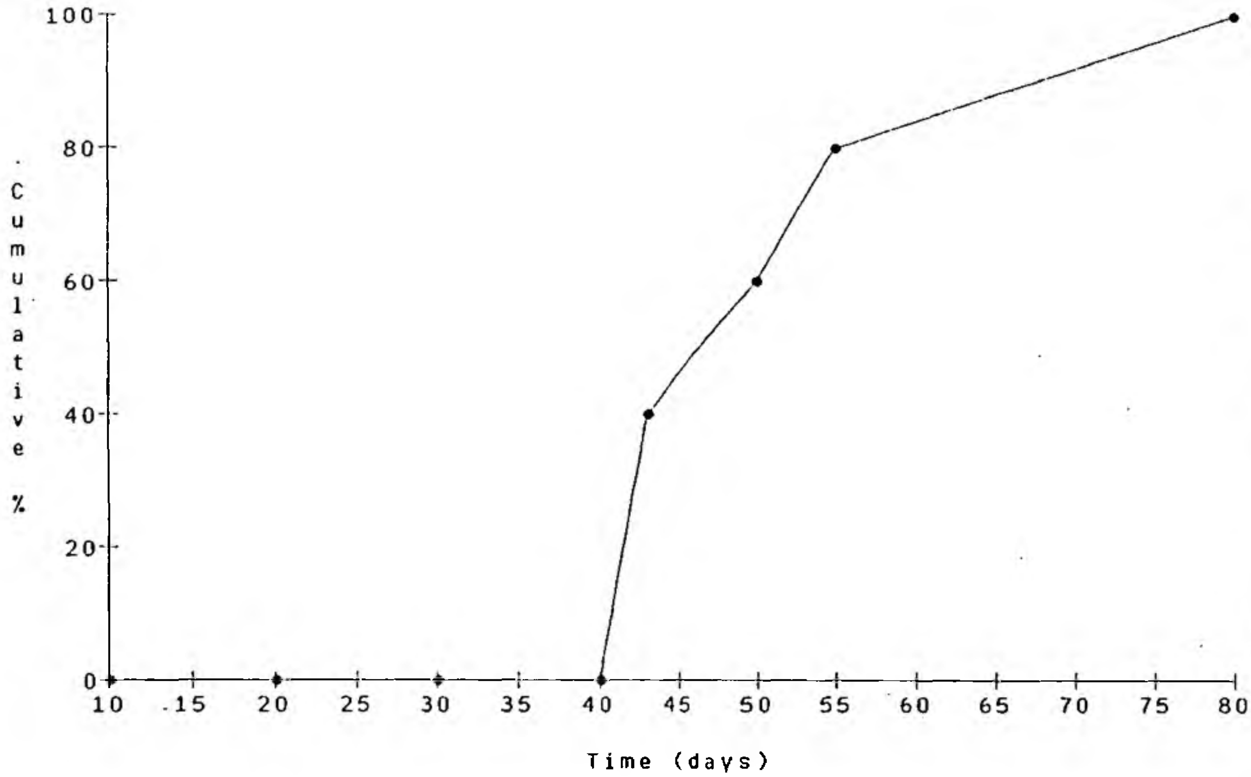

Fig. 10 Highest recorded position vs time of entry from 1 January